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6. AUTHOR(S)
Dr. Plamen Petrov, Jeffrey Hicks, Dr. Alexander Stoyen; 21st Century Systems, Inc. (21CSI)

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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
21st Century Systems, Incorporated
12152 Windsor Hall Way
Herndon VA 20170-2359

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Office of Scientific Research
ATTN: Dr. Robert Sorkin
4015 Wilson Blvd Room 713
Arlington VA 22203-1954

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14. ABSTRACT
This project evaluated a cognitive theory-based conceptual and technical framework for real time information fusion and knowledge management in support of command and control (C2). The intent of this framework is to handle, swiftly and efficiently, the scope and scale of information that characterizes contemporary military C2 environments. The empirical phase of the project was designed to compare the performance of C2 personnel using an advanced information/knowledge management software environment to C2 personnel using a currently deployed software environment. Our goals in this project were to replicate a previous pilot experiment (in which we compared operator performance using an advanced C2 environment to their performance using a standard C2 environment) in two separate C2 domains and to decompose the partial contributions of the differentiating elements of the advanced environment.

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ABSTRACT

This project evaluated a cognitive theory-based conceptual and technical framework for real time information fusion and knowledge management in support of command and control (C2). The intent of this framework is to handle, swiftly and efficiently, the scope and scale of information that characterizes contemporary military C2 environments. The empirical phase of the project was designed to compare the performance of C2 personnel using an advanced information/knowledge management software environment to C2 personnel using a currently deployed software environment. Our goals in this project were to try and replicate a previous pilot experiment (in which we compared operator performance using an advanced C2 environment to their performance using a standard C2 environment) in two separate C2 domains (in this case CVN ACDS and AWACS). These first studies, like the pilot experiment, reflect comparison designs that differed in important ways – any one of which might account for the observed performance differences. Therefore, in a third study, we were to decompose the partial contributions of the differentiating elements of the advanced environment (3d immersion, intelligent decision aids, natural language interface). This study was to yield much more important data regarding the partial contributions of advanced C2 environmental components. This was the primary motivation for our proposal.

1. INTRODUCTION

1.1. Overview

This project sought to evaluate a cognitive theory-based conceptual and technical framework for real time information fusion and knowledge management in support of command and control (C2). The intent of this framework is to handle, swiftly and efficiently, the scope and scale of information that characterizes contemporary military C2 environments. In order to remain operationally relevant, our primary concern was to significantly enhance individual and team-level situation awareness in C2 decision teams.

This project could be accomplished because (1) the theoretical framework is fully articulated and currently implemented in software, (2) the software environment used to implement the framework is robust and easily adapted to domain-specific C2 tasks, (3) we had military customer organizations available to provide subject matter expertise, and (4) we had military research organizations available to provide subjects and data collection workstations. However, with the initiation of a military build-up for Operation Iraqi Freedom, that situation was to change for the worse. Despite commitments for studies from providing organizations, the operators, themselves, became exceedingly scarce.

The empirical phase of the project was designed to compare the performance of C2 personnel using an advanced information/knowledge management software environment to C2 personnel using a currently deployed software environment. This advanced environment provided the following advantages:

1. The tactical situation can be viewed from an immersed 3d perspective in addition to the 2d god's eye view characteristic of standard C2 environments,
2. intelligent software agents continually evaluate the situation and generate actionable recommendations that the C2 personnel can accept or reject,
3. C2 personnel can interact with the advanced environment, including the intelligent software agents using natural spoken language (voice recognition and voice synthesis).

We had recently conducted a very preliminary pilot experiment in which we compared operator performance using an advanced C2 environment to their performance using a standard C2 environment. In this experiment, C2 performance was roughly twice as effective when using the advanced environment, compared to performance using a simulated Aegis C2 environment. Our goals in this project were to try and replicate the pilot experiment in two separate C2 domains (in this case ACDS and AWACS). These first studies, like the pilot experiment, reflect comparison designs that differed in three important ways – any one of which might account for the observed performance differences. Therefore, in a third study, we were to decompose the partial contributions of the differentiating elements of the advanced environment (3d immersion, intelligent

decision aids, natural language interface). This study was to yield much more important data regarding the partial contributions of advanced C2 environmental components. This was the primary motivation for our proposal. But, in the time frame that this third study was to occur, real-world operational commitments superceded our scheduled studies. Even attempts to conduct this last study after the original grant period of performance were unsuccessful due to operations tempo and combat deployments leading to a scarcity of operators. Thus, we used extrapolated data from the first two studies in an attempt to draw conclusions regarding the utility of various components.

1.2. Software Tools

A secondary effect of this work was to provide interested military C2 researchers with a powerful, configurable toolset for ongoing research in advanced C2 support environments – and with the skills necessary to use the tool. This toolset consisted of the AEDGE™ agent environment, tools for scenario, agent and measures development modification, various existing extensions, including built in measures for cognitive science research. This toolset provided the capability for conducting research with single/multiple station(s), in a distributed environment, operating at researcher-selected levels of fidelity (2D, 3D, 2D/3D, aural, etc.) providing a flexible synthetic task environment (STE) for individual and team research in command and control. The importance of such a toolset cannot be overstated.

In response to the capability shortfall for a flexible yet rigorous distributed STE, 21CSI provided our intelligent agent environment, called AEDGE™ and the tools necessary to quickly assemble synthetic task environments. AEDGE provides the complex infrastructure necessary for distributed intelligent applications. And the APIs to AEDGE allow rapid development of flexible STEs tailored to the needs of the researcher. Additionally, 21CSI provided two existing AEDGE applications, AWACS-AEDGE (a 2D team-task environment) and Advanced BattleStation with Decision Support System (ABS/DSS … a 2D/3D correlated battlespace awareness environment), with which researchers can tailor for additional ease in development. 21CSI also provided training using the "train the trainer" concept. Programming support services and updated AEDGE licenses were also provided. This all-inclusive package allowed participating locations participating to conduct state-of-the-art cognitive research with remarkable ease.

A more detailed discussion of the AEDGE architecture and the two provided applications is provided in the appendices.

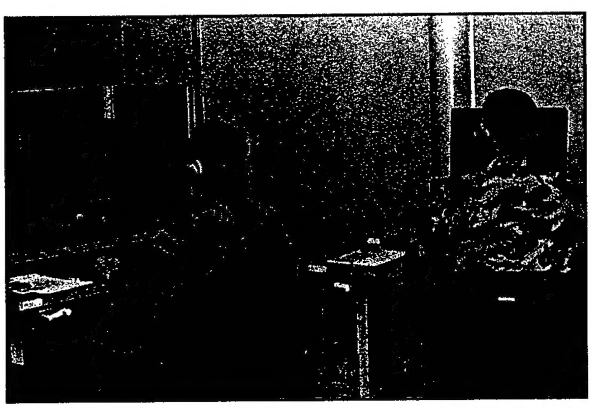
2. REPEATED PILOT STUDY – AWACS DOMAIN

This study is being conducted under the auspices of the Air Force Research Laboratory at Brooks. We piggy-backed on continuing studies conducted by AFRL and their support contractors. These studies investigate complex C3 decision-making under sustained operations under the Warfighter Fatigue Countermeasures program. 21CSI provided updated AEDGE licenses for this study and implemented a number of software changes to the AWACS-AEDGE application for specific use in this study.

The goal of this particular study is "ascertaining effects of sustained operations on decision-making and performance within highly complex multi-operator C4ISR scenarios" [Elliott et al, BRIMS 2003]. The AWACS-AEDGE platform without agent technology and voice recognition was used as the baseline application. A more advanced AWACS-AEDGE application (to include intelligent agent decision support and voice capabilities) will be used in the balance of the study to determine its effectiveness in performance enhancement and as a fatigue countermeasure.

This study utilizes active duty USAF personnel awaiting Air Battle Manager training at Tyndall AFB, FL. Since the associated training and data collection period for each session is taking a week, this study is, at this writing, still in the baseline data collection phase. However, many correlations to previously conducted studies lead us to believe that the results will support our hypothesis.

2.1. Method



This experiment was conducted in the AFRL Cognitive Assessment and Sleep Laboratory (CASL) or in the AFRL facility located at Brooks City-Base. The CASL is a large research facility with rooms for control, preparation, testing, medical examinations, and sleep quarters, and a biochemistry lab.

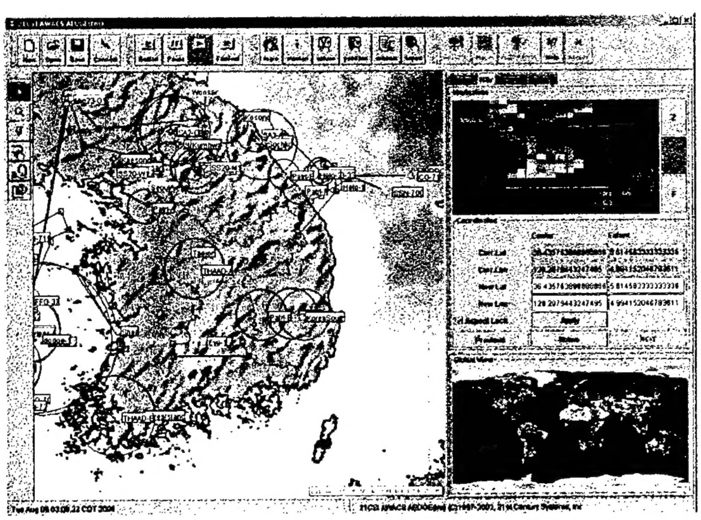
This experiment utilizes active-duty USAF personnel located at Tyndall AFB, FL, who are awaiting initial Air Battle Manager training. Participants experience approximately 30 hours of extensive training in command and control principles, roles, and tactics. They were also taught procedures associated with performance in the AWACS-AEDGE STE; for example, how to manipulate interface features, execute commands, and communicate with others. For the experimental session, they perform scenarios in the STE and on selected cognitive tests, beginning at 6pm and ending at 10am the next day [Elliott et al, 2003].

The C4ISR role was chosen for its operational relevance and importance of command and control to USAF operations. This role requires the coordination of several activities related to finding, verifying, prioritizing, and executing enemy targets within a battlespace scenario [Elliott et al, BRIMS 2003].

The C4ISR role is typically identified by a strong demand for communications, shared awareness, coordinated actions, and adaptive responses to time-sensitive situations. This demand for coordinated action has been intensified in operations by increasing the presence of multi-service and multi-nation tactical actions, requiring ad hoc coordination to circumvent incompatible systems and/or bypass conflicting procedures. Additionally, the complexity of enemy actions and unplanned events are ever present. Changes to operational plans must often be made impromptu in response to unexpected enemy action, changes in weather or terrain, inaccurate information, changing priorities, and/or equipment failures [Elliott et al, BRIMS 2003].

Six 40-minute scenarios were constructed to be "equivalent" in cognitive demand, while avoiding replication and including both complex planned and unplanned events. All six scenarios included 4 roles, three "played" by participants, and one "played" by a software agent. This was to increase complexity while maintaining experiment control. The agent played the least active role, that of HVAA (High-value Assets), controlling assets such as tankers and large ISR assets such as RIVET JOINT [Elliott et al, BRIMS 2003].

The three human roles were as ISR, STRIKE, and SWEEP. The ISR role controlled assets related to ISR function, such as uninhabited aerial vehicles (UAVs). The ISR role's task is to locate and confirm target sites that are in expected areas. They also use assets to perform bomb damage assessment after targeting. The STRIKE role controlled assets such as bombers and jammers. The bombers were used against hostile high-value ground assets such as ballistic missile launchers and surface-to-air missile (SAM) sites. The SWEEP role controlled assets such as fighter aircraft. The fighter aircraft were to be used against enemy air assets, mostly as defensive counter air assets [Elliott et al, BRIMS 2003].



The AWACS-AEDGE, built using 21st Century Systems Inc.'s AEDGE™ infrastructure, is a distributed, real-time team decision support environment comprised of simulators, entity framework, intelligent agents and user interfaces. The environment supports a wide variety of air, sea (surface and sub-surface), and ground assets in a combat environment, primarily based on the roles and responsibilities of AWACS Weapons Director

(WD) team members, but include a variety of military platforms and weapons, with realistic but unclassified capabilities. The environment has been tested with an excess of two hundred physical entities (planes, ships, SAM sites, etc.) operating with realistic performance characteristics in an interactive environment which provides real-time decision support to each WD. The behavior and decision-making of all hostile and friendly entities not controlled by humans is directed by intelligent agent technology. This provides several related capabilities. First, agents "play" all roles not played by a human operator enabling a highly controlled investigation of individual performance within a team setting, where the performance of the other "players" can be controlled. Additionally, this same capability provides optional decision support. If a human decides to "log in" as a particular entity, he/she may choose to view and accept decision support recommendations generated by the agent for that role. Characteristics of agent-based decision-making can be adjusted, such as degree of risk, target priorities, and general accuracy, to enable controlled investigations of performance within various information and decision support contexts [Elliott et al, BRIMS 2003].

Generic resource allocation, search and optimization algorithms are a core part of the AEDGE product. Each AEDGE application can use and further extend these fundamental agent algorithms by either providing parameters and applications specific values, functions and rules, or by combining, modifying or supplying new algorithms. The AWACS-AEDGE application extends resource allocation, optimization and other algorithms with AWACS/WD-specific objective functions and constraints [Petrov et al, 2000, 2002].

Further information on the AEDGE environment is provided in Appendix A. Further specifics on the AWACS-AEDGE application is provided in Appendix B.

2.2. Support

In order to perform an experiment using the C4ISR role in the AWACS-AEDGE application, modifications had to be made to the application to support this kind of role and scenario. Software Engineers and programmers from 21CSI had several discussions with Dr. Elliott and Mr. Dalrymple regarding what tasks the C4ISR role encompasses and what agent behaviors are required to provide decision support (alerting and recommendations based on ROE, situation, etc.) to that role. In addition, discussions on the types of measures that this new role entailed also took place.

21CSI software personnel added new C4ISR-related entities to the synthetic task environment (i.e., UAVs, etc.). The concepts of jamming, decoys, and detection had to be added to the STE framework and the agent behaviors. The concept of sensors and their complementary use (using two sensors plying different spectrums to defeat CCD) was also added. New agent behaviors to support this new role were programmed and implemented. And the Measures Server, that software entity that collects the participant actions and communications was modified to collect the actions associated with this role.

When these changes were complete, 21CSI traveled to the Brooks lab to install the updated software. We updated existing platforms that were already at Brooks and loaded 4 new platforms located in the lab itself. 21CSI also updated the software licenses of the Brooks machines and provided them with additional longevity. Experiment and lab personnel were trained by 21CSI on the changes to the user interface and the scenario development details. 21CSI also collected feedback from investigators that led to additional updates to the platform that were provided electronically.

2.3. Discussion

The investigators in this project are striving for operationally relevant and generalizable results and, thus are being ever so thorough in their process. With the extensive training associated with preparing each subject, the study is taking longer than anticipated. In previous experiments, mission ready WDs were used and the preparations for each subject was much less rigorous.

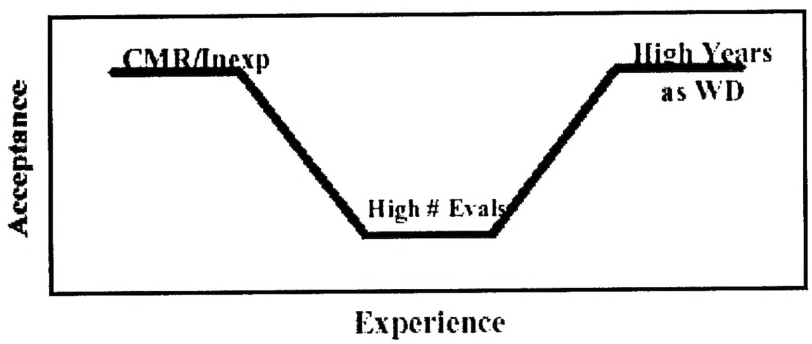
However, those previous studies produced some interesting results that we anticipate will resurface in this study. Two years ago, a large study of AWACS WDs was conducted at Tinker AFB, OK. This study was conducted by the AFRL and the University of South Florida (USF) with the assistance of 21CSI who provided the STE platform and technical support. This team used the precursor to the AWACS-AEDGE (called WD-IAA) and observed 38 WDs from the 552nd Air Combat Wing as they each performed two high-workload missions [Chaiken et al, 2001]. The USF team, led by Dr. Coovert, also administered an experimental STE session using a verbal protocol method and a post-session questionnaire [Coovert et al, 2001].

The published results in Coovert et al, 2001 and Chaiken et al, 2001 were not what the teammembers had initially anticipated. Intuitively, the expectations of the experimenters were that the less experienced WDs would make extensive use of the agent recommendations and the more experienced WDs would more likely ignore those recommendations. Chaiken et al reported that the Likert rating of the WDs indicated that they were conservative in nature. They concluded that the WDs may have preferred not to take the recommendations if they couldn't evaluate the situation concurrently themselves. Thus, the less experienced WDs may have ignored the recommendations since they were unable to "keep up" with the agents. And the more experienced WDs were able to keep up with their evaluation and, consequently, accepted more recommendations that agreed with their assessment [Chaiken et al, 2001].

Coovert et al used a more scientifically rigorous approach using a data mining tool based on Rough Sets Theory. They cited the advantage of rough set theory that it does not make assumptions about the form or distribution of the data. Coovert et al succinctly described the correlation between agent use and WD experience (below) [Coovert et al, 2001].

Results suggest that participants tend to rely on the agent when their experience level suggests they are in the early stages of skill acquisition (e.g., having completed fewer evaluations). That is WDs rely on the agent as a coach or trainer, demonstrating what should be done. In more advanced stages of skill and knowledge acquisition (having completed more evaluations) WDs rely less on the agent, because the WD "knows what to do". Finally, participants who have been WDs for a long time, are confident in their abilities and use agent technology to augment performance. When agent recommendations are consistent with a WD's own plan, accepting recommendations helps execute actions quickly and efficiently.

Coovert et al, 2001



From Coovert et al, 2001

Coovert et al also discussed the relationship between performance and experience with and without agent assistance. The strong correlation between performance and experience changed with the addition of agent assistance. This suggested to them that "...the introduction of an automated agent poses a novel simulation situation in which previous simulator experience does not contribute to performance in the same way as it does when no agent exists" [Coovert et al, 2001].

Thus, we anticipate the current study into the performance enhancement and fatigue countermeasure capabilities of intelligent agent decision support should uncover some of the same results. However, since each participant is awaiting training and receives the same 30+ hours of training, we should get a better look at the actual contributions of intelligent agent decision support.

3. Repeated Pilot Study – CVN ACDS Domain

This study was conducted by 21CSI using Navy watchstanders from the USS Carl Vinson. Through our contacts with the Office of Naval Research and NAVSEA, we arranged for this study to compare use of the existing ACDS system and the new Advanced BattleStation with Decision Support System (ABS/DSS) current in transition for the carrier fleet.

The goal of this particular study was to determine any performance improvements using an advanced C2 application vice a traditional limited C2 application. Scenarios were executed using two separate C2 STE applications, one replicating the existing ACDS application and the other was the new ABS/DSS in its embedded training mode. The ACDS application uses a parochial two dimensional depiction without advanced software techniques. The ABS/DSS, based on the AEDGE platform, utilizes 2D/3D visualization, voice synthesis/recognition, and intelligent agent decision support.

This study utilized active duty USN personnel assigned to the USS Carl Vinson while it was at its home port of Bremerton WA. These personnel were provided from the ship's company, as opposed to staff personnel. The associated training and data collection period took place over the course of a week.

3.1. Method

This study was arranged through US Navy channels as a means to compare the existing C2 application that carrier watchstanders currently use with a new, advanced application that is in the process of being fielded to the carrier fleet. As stated in our proposal, the study was to evaluate the performance of 32 officer and enlisted watchstanders using the two applications. These watchstanders were to be drawn from the ship's actual company of C2 watchstanders. However, as a result of the built up of Naval forces in the CENTCOM AOR in the prelude to Operation Iraqi Freedom, the ship's leadership reduced their support for this study to 8 personnel, four officers and four enlisted.

The study was conducted in facilities at Olympic College in the Bremerton area. In order to make up for the personnel shortfall, each participant was scheduled to perform in three increasingly complex scenarios. Also, due to the reduced personnel support, only three of the six scenarios prepared for this study were used.

In preparation for the study, six scenarios were developed…essentially two sets of three scenarios of increasing complexity. Three emulated a fray in the Taiwan-China AOI and three emulated a Korean peninsula situation. Each set of three scenarios were of increasing complexity. The first in the set of three involved controlling 3 attack aircraft and a tanker asset. For example, Taiwan-1 outlined a scenario where the primary mission was to control escalation between the PRC and Taiwan with a secondary mission of defending the carrier and a friendly base on Taiwan. The watchstander controlled 2 F-

18s, 1 F-14, and a T-1 Tanker. The second scenario in a set involved controlling more and different assets under the same primary and secondary missions. In Taiwan-2, the watchstanders handled subsurface, surface and air assets and reacted to subsurface, surface, and air threats. The third in the sequence of scenarios added a TBM facet to the fray.

Since each participant needed to perform several scenarios, each was afforded the opportunity to perform these tasks on the ACDS and ABS/DSS platforms. However, they were not allowed to perform an identical scenario on the differing systems. The ACDS STE was a two dimensional depiction which used line drawings to show the coastline and used standard ACDS icons to depict the entities in the STE. On the other hand, the ABS/DSS is an advanced C2 application that incorporates two dimensional and three dimensional depictions using digital terrain and elevation data (DTED) and digital bathymetric data, voice synthesis for alerts and recommendations, voice recognition for giving commands, and intelligent agent technology for alerting the user to relevant situations and for determining appropriate courses of actions given the situation. The ABS/DSS is normally operated using a headset (with earphone and a microphone), a mouse, and a joystick.

3.2. Support

This study was conducted at Olympic College in Bremerton WA. Dr. Regian and 21CSI systems support personnel set up and conducted the study. Several high-end computer workstations were set up and networked together. Large video monitors were used to provide more than adequate visual depictions of both applications. Each setup was tested before it was put into actual study use.

Each participant was given instruction on the use of each STE and the associated user interface devices (joysticks, headsets, etc.). Additionally, presentations and handouts were given describing each scenario's missions, goals, and environment.

Both STEs captures a number of measures from the participant's actions and performance. These measures included mouse-clicks, displays opened, communication actions, and a running logoff the state of the simulator's environment. This data was further reduced to the number and timing of pertinent events and user actions. This reduced data was then ported to Excel spreadsheets to take advantage of its inherent graphing capability.

3.3. Discussion

The differences in the two C2 applications provide a unique look at the benefits offered by a more advanced situational awareness computer application. Several of the participants, while they used the 3D visualizations, felt that these didn't provide as much

benefit as the alerts and recommendations provided by the intelligent agent technology did. And the processed data bore out these observations.

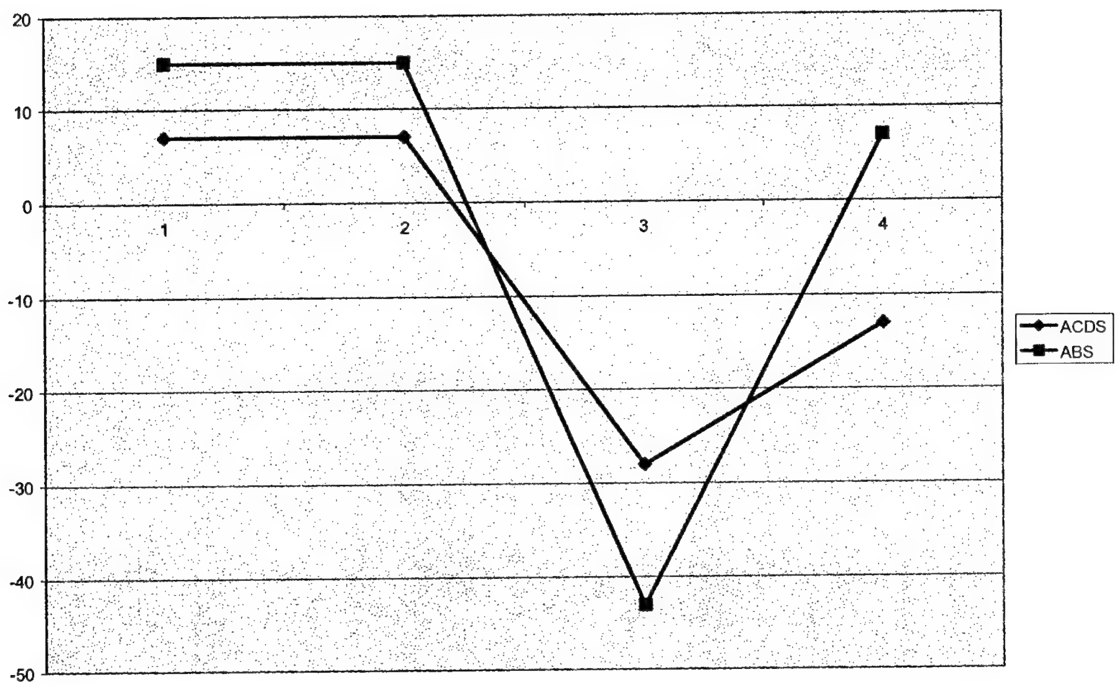
Most of the users were able to perform the stated mission and meet the goals of the scenario using either C2 application. But the differences became readily apparent in the speed of decisions and the handling of assets on the periphery of the situation. There were a few situations in the scenarios where a very quick reaction was necessary to avoid losing an asset. Also an artificiality of the simulation was the willingness of a simulated aircraft to run out of fuel. If the attention of the participant was drawn away from this situation, it did not take care of itself and the asset flamed out and crashed. Decision support technology is tailor-made for these two types of situations (as well as many others).

Overall, the performance of each participant was scored using a weighted score based on the enemy assets destroyed and the friendly assets lost. Weights were derived to accentuate various facets of the scenarios (quick reaction, inattention, etc.). The formula is provided below.

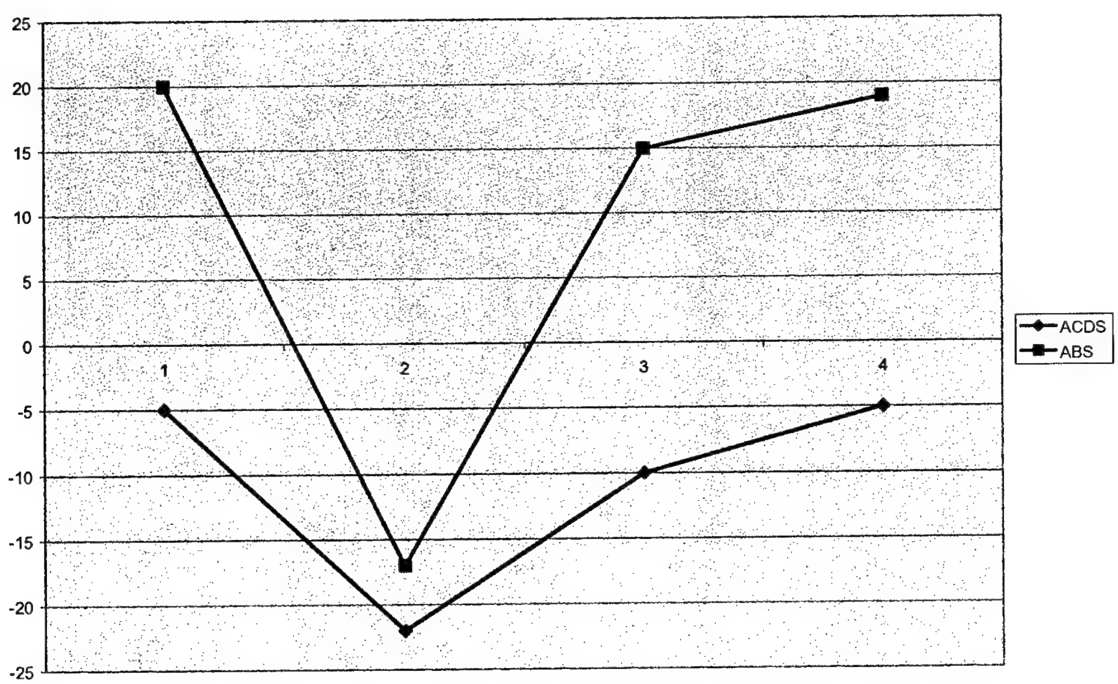
> *score = w1*killed_mig23s/killed_HVAAs + w2*killed_missiles + w3*killed_sams + w4*killed_submarines - w5*lost_helos - w6*lost_F15s - w7*lost_14s - w8*lost_HVAAs - w9*fuelouts*
>
> *(aircraft that were lost due to fuelout are not counted as lost -- i.e. counted only once, as fuelouts)*
>
> *The weight factors w1, ..., w9 were as follows:*
>
> *w1=5*
> *w2=10*
> *w3=1*
> *w4=2*
> *w5=5*
> *w6=10*
> *w7=8*
> *w8=15*
> *w9=20*

The overall score comparison results are depicted below.

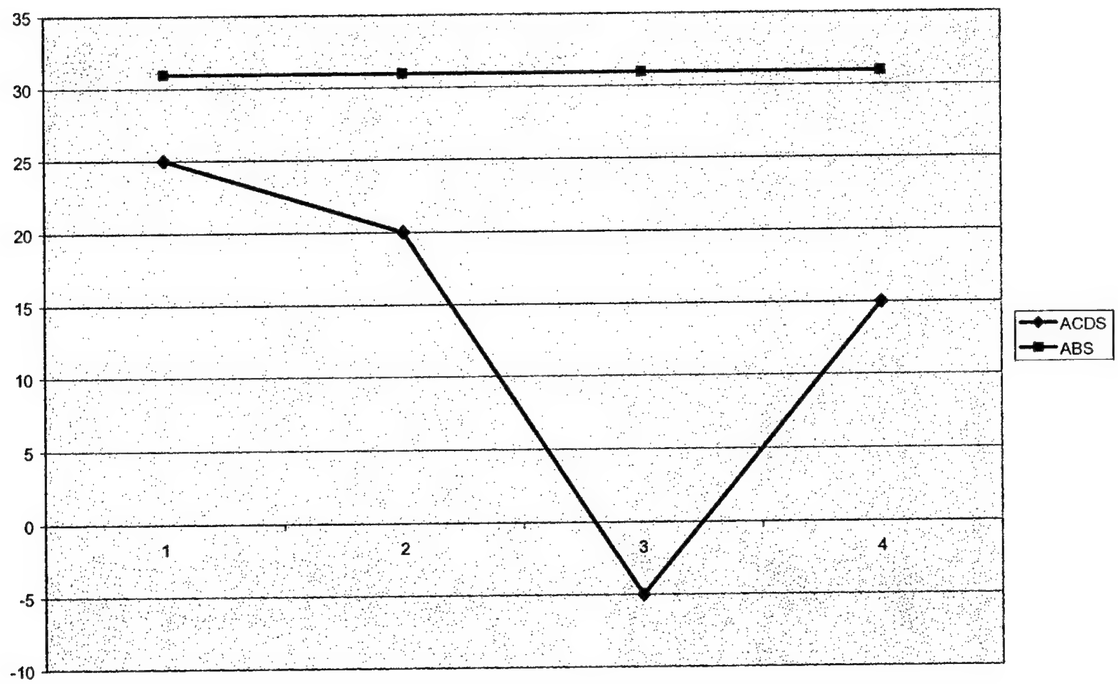
Taiwan-1 Score



Taiwan-2 Score

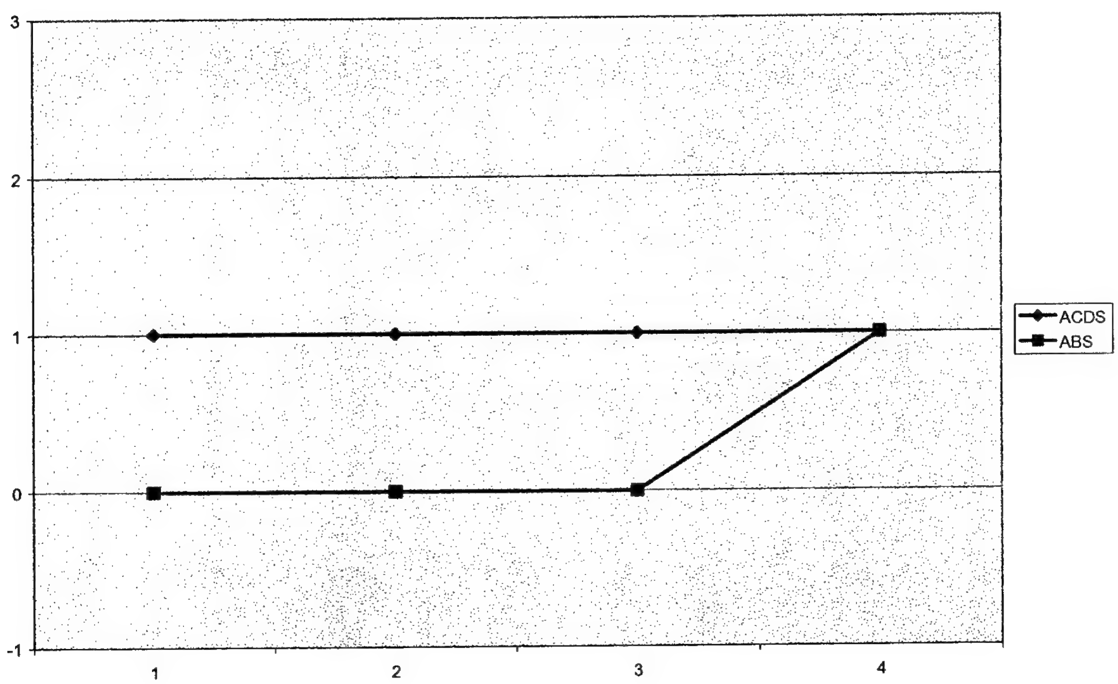


Taiwan-3 Score

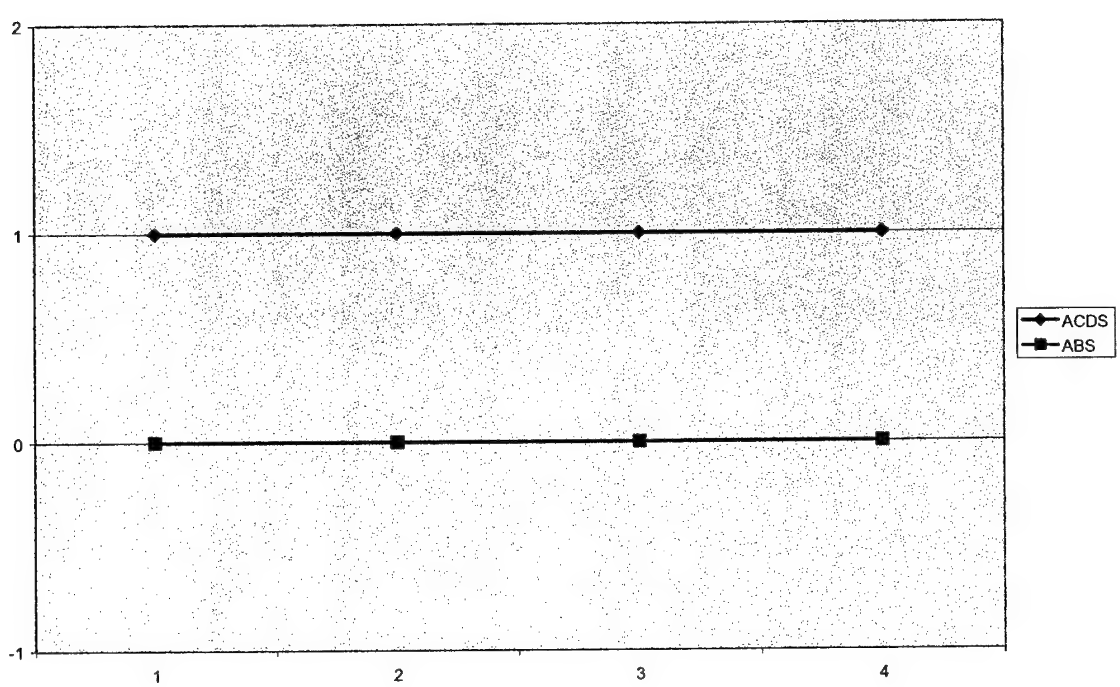


In particular, two next sets of graphics show the added value of the agent technology. In the more complex scenarios, the number of assets lost due to action and the number of assets lost due to inaction ("fuelout") clearly show a distinct difference when agent technology is used vice when it is not available. Obviously, given the relatively small sample set, it is difficult to extrapolate this conclusion to a much wider situation, but it is not unexpected.

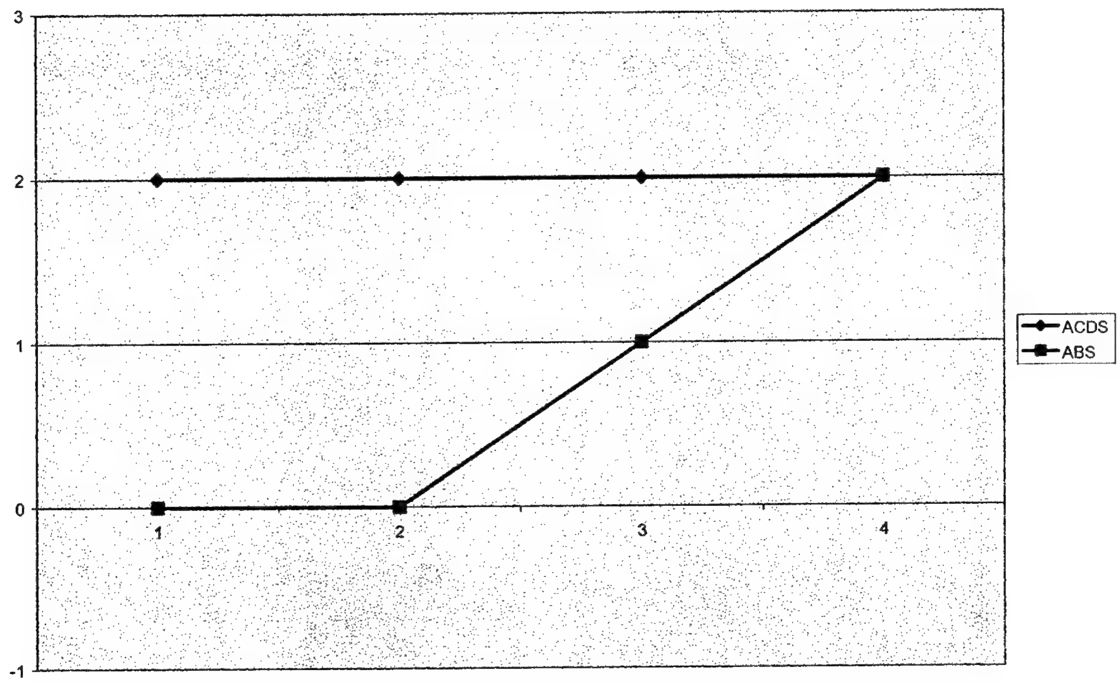
Taiwan-2 Fuelouts



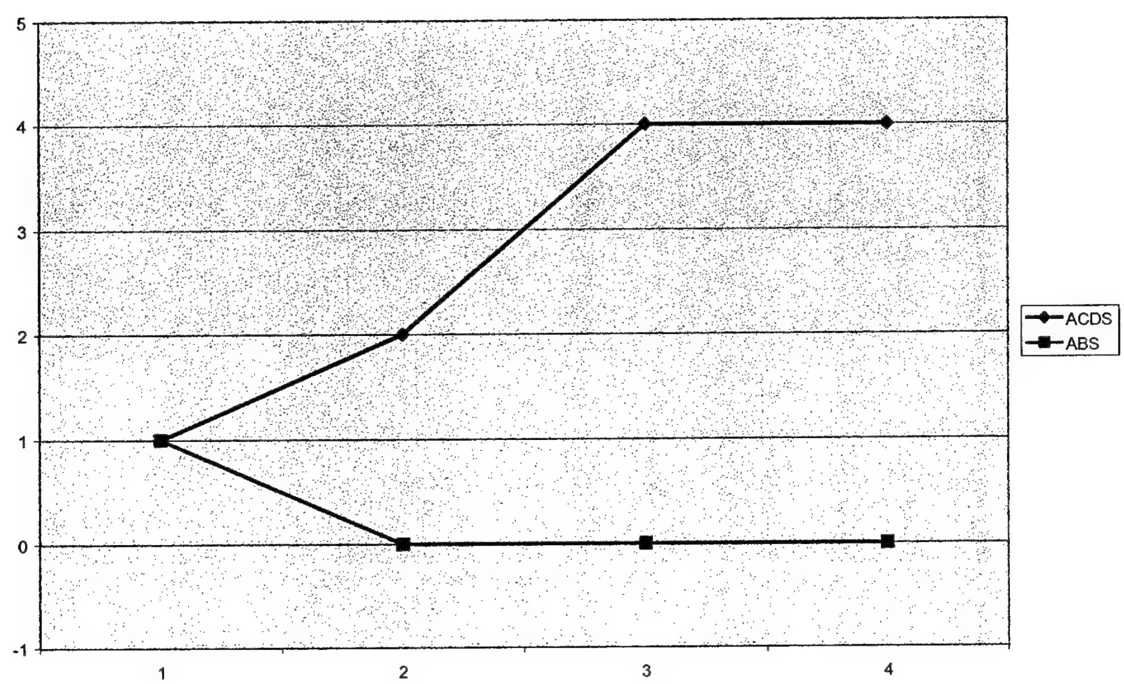
Taiwan-3 Fuelouts



Taiwan-2 Assets Lost



Taiwan-3 Assets Lost



The results of this study served to support the results from the pilot study. The addition of intelligent agent decision support allowed the participant to close the decision loop faster while keeping the "human in the loop." Participant comments also served to reinforce this idea. And, while the immersive displays and multiple user interface capability made the application easier to operate, it was the decision support that actually made the most difference.

4. Advanced Environment Component Study

In this third study, we were to decompose the partial contributions of the differentiating elements of the advanced environment (3d immersion, intelligent decision aids, natural language interface). This study was to yield much more important data regarding the partial contributions of advanced C2 environmental components. This was the primary motivation for this entire project. But, in the time frame that this third study was to occur, real-world operational commitments superceded our scheduled studies. Even attempts to conduct this last study after the original grant period of performance were unsuccessful due to operations tempo and combat deployments leading to a scarcity of operators. Thus, we used extrapolated data from the first two studies in an attempt to draw conclusions regarding the utility of various components.

4.1. Method

We made arrangements with ONR and NAVSEA to return to the Bremerton area and conduct further tests with the crew of the USS Carl Vinson. This test was scheduled in the early portion of this grant's scheduled period of performance. We were to install on the ABS/DSS application on the ship and conduct training and tests at that time. However, the Vinson's training schedule was accelerated for an early real world sailing and the install and test didn't take place.

After extensive coordination with NAVSEA, we arranged another opportunity to install and run studies on the USS John Stennis in San Diego. This was scheduled to occur after the end of the period of performance of the grant, but we continued anyway in an attempt to glean valuable data. We arranged for 2 weeks (10 days) of training/testing six personnel per day. This was to be followed by at sea trials and further testing. Unfortunately, despite the crew's willingness to participate, NAVSEA cancelled these tests at the last minute in order for the Stennis to get underway for real world taskings.

Since operations tempo and real world commitments related to Operation Iraqi Freedom preempted our attempts to study the contributions of the various components of an advanced C2 application, we were forced to look at our previous studies and several studies of others in order to draw some conclusions on this subject. Dr. Jared Freeman of Aptima has done similar studies for ONR and others and we referenced some of his work as well (see Freeman et alia, CCRTS 2002; Freeman et al, 1998; and Freeman and Cohen, 1998).

4.2. Discussion

As stated previously, an advanced C2 application differed from the parochial application in that the advanced application (1) provided the tactical situation in an immersed 3D perspective similar to that of 3D gaming software in addition to the 2D god's eye view

characteristic of parochial C2 environments; (2) allowed C2 personnel to interact with the advanced application, including the intelligent software agents, using natural spoken language; and (3) provided intelligent software agents continually evaluating the situation and generating alerts and actionable recommendations that the C2 personnel can accept or reject. We shall discuss each of these facets is greater detail below.

4.2.1. Three Dimensional Perspective

The advanced visualization techniques attempt to take advantage of the digitization of our world and present the battlespace in a spatially correct depiction. Using NIMA's digital terrain and elevation data (DTED) and NAVSEA's digital bathymetric database (DBDB-V), the battlespace is graphically depicted on a computer screen. Combatants are depicted within this environment and geospatial relationships (such as proximity, line-of-sight, different realms, etc.) become intuitively obvious. This accelerates the watchstander's assimilation of the situation and allows the watchstander to close the decision loop faster.

But the utility of this type of visualization is useful only to battlespace environments where issues of disparate realms and line-of-sight are an issue. In a pure air engagement, for example, where the battlespace remains in a single realm (the air realm…as opposed to the surface, subsurface, or space realms), many of the advantages provided by an immersive visualization are offset by other disadvantages. The homogenous expanse of the air realm and the ease of traversing through it by aircraft and weapons makes a two dimensional visualization most adequate for this type of battlespace visualization.

However, when the battlespace covers more than one realm or covers a single realm where issues within the realm (e.g., line-of-sight, water density, salinity, etc.) impact mission execution, then an immersive visualization can provide the watchstander with an accurate depiction and allow him/her to assimilate the situation more quickly. This is particularly true in surface, subsurface, and littoral warfare.

And this was borne out in many of the post study discussions with study participants. The adage of a picture being worth a thousand words is exponentially true in the case of an immersive visualization.

4.2.2. Natural Spoken Language

This facet of the advanced C2 application involves allowing the watchstander to interface with the application using speech. In reality, this is actually two capabilities … speech synthesis and speech recognition. Speech synthesis is the capability of the C2 application to generate speech (via headset or speakers) in order to inform or alert the watchstander. The second capability is speech recognition where the user can provide inputs and commands to the C2 application using voice.

Speech synthesis is the easier of the two capabilities to implement. The C2 application generates a text string and uses a service known as Text-to-Speech (TTS) that is provided by several vendors (IBM, Microsoft, and others) to render the speech. Since the application is merely converting a text string to generic speech, issues such as accent and tempo are not an issue. The application simply speaks to the user. However, many TTS engines provide the capability to alter the speed and pitch of the voice in order to provide the illusion of "urgency" in the voice.

Speech recognition is the more challenging capability to implement well. There are many tradeoffs when implementing this type of interface. Since the speech recognizer does not "know the context" of each of the commands, it must be given a context or it must be allowed to try and determine one. One can provide this context to the computer in the form of a grammar (an ontology implemented in a markup language). This grammar tells the recognizer the things the watchstander will say and the possible order in which they will be said. Anything not in the grammar is not recognized and ignored. Using a grammar makes the recognizer faster but it constrains what the watchstander can say and how they can say it. The alternative is to allow the watchstander to speak freely and make the recognizer work out what was said. Since no person speaks the same as another, the watchstander would have to "train" the recognizer. Also, the recognizer would require more processor time in order to determine the context and properly convert the phonemes (snippets of sound) into the proper words.

This ability to interface with the C2 application using natural speech is the next logical step in user interface evolution. This method of UI frees the watchstander's hands for other actions. Yes, a watchstander can operate most applications without this type of interface. But, like the manual typewriter, the other means of interface will be pushed out for this more innovative and easier-to-use UI technology.

4.2.3. Intelligent Agent and Decision Support System (DSS) Technology

This facet of the advanced C2 application involves aiding the watchstander in closing the decision loop faster. Intelligent software agents are semi-autonomous threads of running software that monitor the watchstander's electronic environment. Their function is to alert the watchstander to situations within the environment that the watchstander has defined as "of interest." This intelligent agent can also assist the watchstander by highlighting the visualization in a manner that speeds situation recognition and by providing a specific recommendation to address this event based on the current situation (ROE, etc.) and available resources. This keeps the human-in-the-loop and allows more rapid decision cycles.

This facet of the advanced C2 application is reported, in general, by study participants as the most useful. Coovert et al, 2001 and Chaiken et al, 2001 reported in their studies that this decision support facet is very important. That is, if the watchstander chooses to take advantage of the offered decision support service. Chaiken et al concluded that the WDs may have preferred not to take the recommendations if they couldn't evaluate the

situation concurrently themselves. Thus, the less experienced WDs may have ignored the recommendations since they were unable to "keep up" with the agents. And the more experienced WDs were able to keep up with their evaluation and, consequently, accepted more recommendations that agreed with their assessment [Chaiken et al, 2001].

Dr. Jared Freeman has also documented the effects of decision support technology on tactical decision making [see Freeman et al, 1998; Freeman & Cohen, 1998; and Freeman et al, CCRTS 2002]. Dr. Freeman et al identified the two modes decision making in tactical situations. Recognitional decision making was based on recognizing at situation and making an appropriate response. This mode is prevalent when the situation is very familiar, the stakes are low, and time is short. When the situation was new, the stakes were high, and time was available, critical thinking was appropriate. Critical thinking was the weighing of evidence and evaluation of options [Freeman et al, 1998].

In his work, Freeman documented that decision support treatments improved decision outcomes. He also noted a trend for DSS treatments to lower watchstander frustration by approximately 16% [Freeman et al, 1998]. While Freeman was focused on DSS impact to critical thinking, it is intuitively obvious to the most casual observer that DSS technology can speed recognitional decision making immensely. This DSS technology can also provide the watchstander with indications that information uncertainty, available time, and the stakes warrant the use of critical thinking instead of the snap decision of the recognitional mode. Freeman noted this as well [Freeman et al, 1998; Freeman & Cohen, 1998]. This kind of assistance could have a significant impact in potential friendly fire situations.

5. Conclusion

This project evaluated a cognitive theory-based conceptual and technical framework for real time information fusion and knowledge management in support of command and control (C2). The intent of this framework is to handle, swiftly and efficiently, the scope and scale of information that characterizes contemporary military C2 environments. The empirical phase of the project was designed to compare the performance of C2 personnel using an advanced information/knowledge management software environment to C2 personnel using a currently deployed software environment. Our goals in this project were to replicate a previous pilot experiment (in which we compared operator performance using an advanced C2 environment to their performance using a standard C2 environment) in two separate C2 domains and to decompose the partial contributions of the differentiating elements of the advanced environment.

We conducted a very preliminary pilot experiment in which we compared performance using the Advanced C2 environment to performance using the Standard C2 environment. In this experiment, C2 performance was roughly twice as effective when using the Advanced environment, compared to performance using a simulated Aegis C2 environment.

We extended this study to the AWACS Weapons Director (WD) domain by piggy-backing on continuing studies conducted by AFRL and their support contractors. These studies investigate complex C3 decision-making under sustained operations under the Warfighter Fatigue Countermeasures program. 21CSI provided updated AEDGE licenses for this study and implemented a number of software changes to the AWACS-AEDGE application for specific use in this study. The AWACS-AEDGE platform without agent technology and voice recognition was used as the baseline application. A more advanced AWACS-AEDGE application (to include intelligent agent decision support and voice capabilities) will be used in the balance of the study to determine its effectiveness in performance enhancement and as a fatigue countermeasure. This study utilizes active duty USAF personnel awaiting Air Battle Manager training at Tyndall AFB, FL.

We also extended the study to Navy watchstanders from the USS Carl Vinson. Through our contacts with the Office of Naval Research and NAVSEA, we arranged for this study to compare use of the existing ACDS system and the new Advanced BattleStation with Decision Support System (ABS/DSS) current in transition for the carrier fleet. The goal of this particular study was also to determine any performance improvements using an advanced C2 application vice a traditional limited C2 application. Scenarios were executed using two separate C2 STE applications, one replicating the existing ACDS application and the other was the new ABS/DSS in its embedded training mode. The ACDS application uses a parochial two dimensional depiction without advanced software techniques. The ABS/DSS, based on the AEDGE platform, utilizes 2D/3D visualization, voice synthesis/recognition, and intelligent agent decision support. This study utilized active duty USN personnel assigned to the USS Carl Vinson while it was at its home port of Bremerton WA. These personnel were provided from the ship's company, as opposed to staff personnel.

In the third study, we were to decompose the partial contributions of the differentiating elements of the advanced environment (3d immersion, intelligent decision aids, natural language interface). This study was to yield much more important data regarding the partial contributions of advanced C2 environmental components. This was the primary motivation for this entire project. But, in the time frame that this third study was to occur, real-world operational commitments superceded our scheduled studies. Even attempts to conduct this last study after the original grant period of performance were unsuccessful due to operations tempo and combat deployments leading to a scarcity of operators. Thus, we used extrapolated data from the first two studies and reports from similar work in an attempt to draw conclusions regarding the utility of various components.

It is evident that the improved performance from using an Advanced C2 application over a parochial type of C2 application makes the decision for adopting this type of technology an easy one. However, the individual facets of the Advanced C2 application can vary and the most important ones are those that aid the watchstander in closing the decision loop faster in recognitional decision making and provide important clues as to when the watchstander can and should use the more methodical critical thinking mode.

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Appendix A – AEDGE Distributed C2 Research Environment

A.1. Overview

This program consists of five major parts: AEDGE environment, AEDGE APIs, AEDGE extensions, training, and support. Each will be discussed in this section.

A.2. AEDGE™ Environment

21CSI's extensible multi-component Decision Support Systems (DSS) architecture, known as AEDGE™, is a standardized Commercial off the Shelf (COTS), DII-COE compliant agent architecture that enables complex DSS to be developed as an expansion of the AEDGE™ core functionality. The need for a standardized common infrastructure has led 21CSI to design an environment where both agents and real/simulated entities (or representations of real-world assets) are represented as first-class objects, capable of interacting with each other. The AEDGE™ is 21CSI's undertaking to build a common reference framework and a test-bed environment for integrated simulation and agent-based decision support. The architecture describes the data objects, interfaces, communication mechanisms, component interactions, and integration mechanisms for the AEDGE™ and its extensions. In this section we will introduce the AEDGE™ Architecture.

A.2.1. AEDGE™ Information Flow

The AEDGE Information Layer provides data format definitions (data Objects) and information flow descriptions. As part of the AEDGE infrastructure, four major packages of data Classes are defined. These classes form the base AEDGE information environment, which supports persistent and remote data access through serializable data.

Geographic and Terrain Data. These define locations, routes, and geographic areas, with their coordinates, elevations, and properties. For example, terrain properties (elevation, soil type, vegetation, etc.) are stored in TerrainData objects. Coordinates and locations are encoded by Location objects, which also define unique names for the locations.

Entity and Track Data. This hierarchical set of classes defines the data objects associated with track information. Entities are characterized with their speed, heading, fuel status, and so on. Targets carry priority and classification data, while Platforms contain information about the weapons and sensors carried onboard.

Agent Data. While Agents are mostly functional entities and not typically data-heavy objects, some Agents may choose to preserve some or all of their data in a serializable (or persistent) format. Such Agents will be able to store and modify their characteristics as well as possess the ability to migrate among network nodes.

Metrics and Measures Data. As part of the AEDGE information infrastructure, performance, scoring and other measures and metrics are supported. The Metrics and Measures package defines the data classes for storing and exchange of metrics data. These include Trainee Scores, Communication Measures, Load Measures, Interaction Measures, and so forth.

Data-Bridge Interfaces. Though not part of the Information Layer, the data bridges are essential components of the AEDGE infrastructure as they provide connectivity to external, components, and information sources. External information sources, such as DIS/HLA compliant simulators, Sensor Feeds, Standard Databases, instrumentation and monitoring and visualization tools, etc. can be connected and interact with the AEDGE through a variety of data bridges.

A.2.2. AEDGE Components and Services

21CSI's AEDGE components are the base software units providing various functionalities to the user and to other components. Figure A-1 shows these base units.

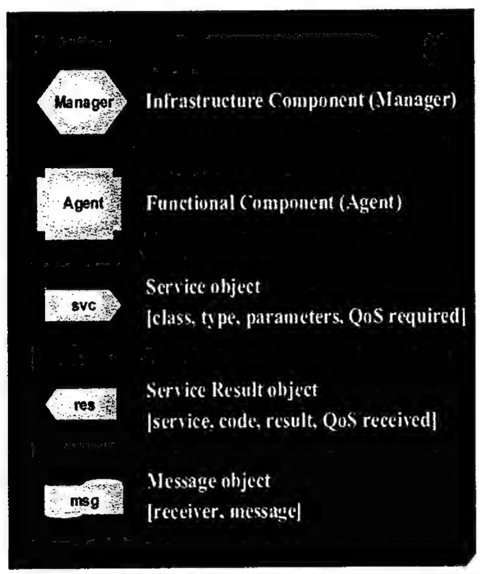


Figure A-1. AEDGE base components and services

Infrastructure Components provide connectivity and manage other components. All Functional Components encode algorithms for various types of processing. Components communicate to each other by sending Service Requests (using the Service object to store the request data) and receiving Service Results. When a Service Provider component needs to send a message to one or more of its "clients," or Service Requestors subscribed to it, a simpler Message object is used for efficiency. The message can advertise service availability at the sender component or it may provide a one-time notification or information item.

A.2.3. Component interactions

In the AEDGE architecture, components communicate among each other via the Service Provider/Service Requester Protocol (SPSR). Service providers are components that implement an algorithm or need to share their data (data sources). Service requesters are the components that need a function performed for them by some other component or need to import data from another component. Both service requesters and service providers implement remote interfaces, which enables such components to communicate over a TCP/IP network. The remote interface implementation is currently based on Java RMI (remote method invocation, a type of simplified Object Request Broker, or ORB, service). The AEDGE Architecture is flexible to provide alternative implementations, such as XML-RPC based interface or direct TCP/IP socket interface.

The SPSR protocol is based on three data objects: Service, ServiceResult and Message. The Service object encapsulates the class, the type, the required quality of service (QoS) and the parameters of a service request. The ServiceResult object provides a reference to the original service, a return code (success or failure), a return object (String, Recommendation, etc), and an actual received QoS. Messages provide a way of service providers to advertise the availability of new services and to notify subscribers of new data available.

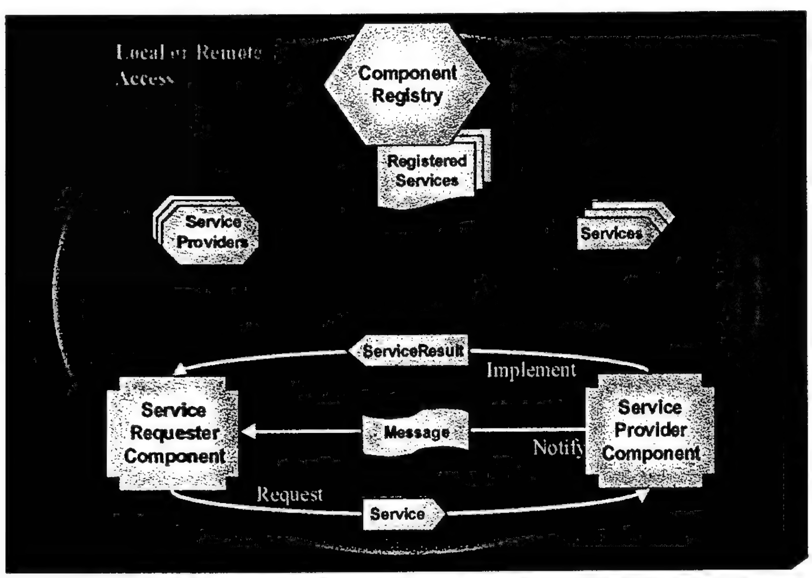


Figure A-2. AEDGE SPSR protocol interactions

Service provider components register their location and the services they provide with a Component Registry, which is responsible for tracking and maintaining service provider information. Service requesters lookup service provider information from the Component Registry and then establish a direct connection with the providers they wish to engage. A service request (either blocking or non-blocking) is sent from the service

requestor to the service provider. The provider then replies (immediately or at some future time with a ServiceResult).

A.2.4. Agents and agent interactions

Agents in AEDGE are specialized components that monitor and analyze data and generate recommendations either in response to a user inquiry or spontaneously, according to their function. Agents are usually organized in agent communities, unified under an Agent Manager component, which is responsible for invoking and synchronizing individual agents.

The Agent Manager interacts with agents via the SPSR protocol, while users (through UIs) interact with the Agent Manager through more user-friendly Inquiry/Recommendation Exchange Protocol (IREP). The users can query the agent manager by sending context information (entities, geo-references, target information, etc.) and specific requests for recommendations. The query is internally translated to service requests and sent to the Agent Manager. The users are not limited to the IREP – they can use any query representation, such as SQL queries, as long as they can be internally converted to service requests.

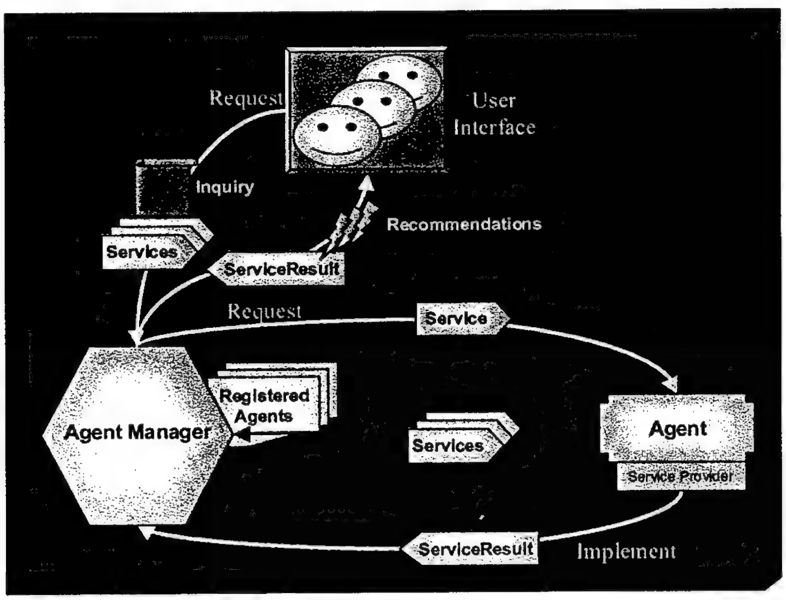


Figure A-3. Agent Components over AEDGE services

Upon receiving a user-level query, the Agent Manager selects and invokes the appropriate agents to perform the desired tasks. The Agent Manager has a table of registered Agents and their capabilities. Thus, the Agent Manager is the one that partitions the problem, sends sub-tasks to the individual Agents, and later combines and deconflicts the solutions. After an overall solution is reached, the Agent Manager forms a set of recommendations, which are returned to the User via a ServiceResult object. In essence the IREP is a user-friendly protocol build on top of the SPSR protocol.

The interactions among agents and the Agent Manager are solely based on the SPSR protocol, as these are optimized for efficiency and not necessarily for user-friendliness. The four different modes of User/Agent-Manager/Agent interactions are described below.

a) **User to Agent Manager Interactions**. Essentially the user sends an inquiry to the Agent Manager, based on the user's current needs and query representation language. The inquiry may consist of a task description and optionally a context update, such as platforms, targets, geo-references etc. The inquiry is internally serialized and translated into service requests, which are then sent to the Agent Manager via the SPSR protocol. After the Agent Manager performs the requested tasks, it sends a reply in the form of a set of recommendations. Recommendations are core objects in AEDGE's framework, which represent desired actions and commands. Recommendations may be produced by both Agent Managers and users and are interpreted by Entities to form tasks and orders. In this case Recommendations are generated by the Agent Manager and sent for approval to the User.

b) **Agent Manager to Individual Agents**. In this interaction the Agent Manager partitions the task to subtasks for the individual agents, registered under the Manager. Subtasks are then sent to the agents via the SPSR protocol, encapsulated in Service objects. After the individual agents arrive at a solution they respond to the Agent Manager with ServiceResult objects, which are interpreted by the Manager. The Agent manager performs synchronization and deconfliction of the individual agents' results to ensure that the user will receive a coherent set of recommendations (in case individual agents had provided conflicting information).

c) **User bypasses Agent Manager**. The user can interface directly with the individual agents, using the SPSR protocol. If the user process can locate the Service Provider of an agent (via a Component Manager where that agent is registered), the user can send service requests directly to the agent and listen for the ServiceResult object in the reply. This places the burden of locating and interfacing with the agent's service provider on the user, but it provides more flexibility and faster response.

d) **Agent-Direct interaction**. Agents can communicate with each other indirectly (through the Agent Manager) or directly, via the SPSR protocol. The Requester agent looks up other agents' service providers from any component manager (including the Agent Manager) and can then send service requests to other individual agents. The Provider Agent handles the service request just like it would handle a request from the Agent Manager. The Requester agent needs to be able to handle the ServiceResult returned by the Provider. Agent-direct interaction provides the flexibility of extending the agent community that belongs to an Agent Manager without having to modify the login of the Manager itself.

A.2.5. Measures

The AEDGE architecture provides for an implementation that is instrumented with hooks and stubs for monitoring and logging of various control variables. A number of measures are pre-defined and built into the architecture. Other measures can be easily defined by the user prior to exercise execution or even during run-time. In the current implementation, the AEDGE supports the following types of measures.

- **User interactions**. All user interactions with the software are logged including mouse clicks, keyboard strokes, and voice commands. The researcher can define filters and use hooks to ignore or target specific types of interactions.
- **Communications**. All communications over the AEDGE's Comm channels are captured and logged. Communications can take place between any pair of human users, agents, simulated entities, or simulated teammates. The researcher is free to filter any type of communication that is not of interest.
- **Agent interactions and recommendations**. As multiple agents interact to reason and to produce a set of recommendations, the interaction events, as well as the final set of recommended actions can be observed and logged. Logging agent recommendations, even if they are not displayed to the human user can be of significant benefit, as a baseline for evaluating the human decisions. A number of filters can be utilized to target specific types of agent interactions or recommendations.
- **Cognitive workload measures**. A number of cognitive workload measures for AWACS Weapons Directors (WDs) have been defined (Schiflett, Elliott, Dalrymple) and implemented as part of the AWACS-AEDGE (see Section B.4 Extensions). These include number of engaged hostiles, number of kills, number of intruders (covered/not covered) and so on. Specific combinations of these data points are known to closely correspond to the cognitive workload of AWACS WDs, and thus they are captured for feedback and analysis. Other application-specific measures can be constructed in the same manner.
- **Scenario Complexity Dimensions.** Closely related to cognitive workload measures, task complexity dimensions allow comparison of experimental results derived from scenarios that differ on surface characteristics (such as tanks versus ships). Examples are information uncertainty levels (trusted versus untrusted information), information veracity levels (true versus false information) operations tempo (frequency of significant events per unit time), event noise ratio (ratio of informative to irrelevant information), friendly entities (quantity, strength, and aggressiveness of friendly forces), resource limitations (availability and sufficiency of forces, munitions, and materiel), friendly resource requirement conflicts (overlapping resource requests), hostile entities (quantity, strength, and aggressiveness of hostiles)
- **Human performance scoring**. Human decisions are measured and scored by a set of pre-defined scoring functions, based on the factual outcomes of engagements, maneuvers, aerial refueling, and other operational elements. Scores are user-definable combinations of various measured data points (e.g. number of hostile kills). Scoring based on the comparison to agent-recommended actions is

also available. Both individual and team scores can be defined to reflect the team-oriented nature of the WD task.

- **Simulation events**. All or any subset of the simulation events supported by AEDGE's Joint Force Open Component Simulator (JFOCS) can be logged for subsequent examination. The events cover all aspects of the simulated entities, from position updates to mission execution, weapons released, target status and so on. Command and control input from the users (or agents) is also logged, to indicate the source and rationale behind mission changes.

All measures are being logged to structured files and can be examined, combined, or processed in a post-mortem analysis. Filters and operators over measured events are also provided, so that the researcher can define and test correlation hypotheses as well as complex cause-effect propositions based on the collected data. Measures can also be examined in real-time, while the exercise is still in progress.

In addition to the pre-defined measures, completely new measures can be constructed, logged and analyzed through the same infrastructure. Using the built-in hooks and triggers, the user can define events as well as qualitative and quantitative measures that can be observed and logged by the existing measures services.

A.2.6. Scenario Generator and Scenario Editor

The AEDGE product has two mechanisms with which to produce a scenario for the simulation. There is a preexisting scenario generator as a component of the AEDGE™ architecture. The Scenario Generator is menu driven and has the capability for a researcher to compose a scenario that will meet particular objectives with a variety of different types of contacts with varied tactics and behavior. The Scenario Generator is easy to use and will reduce the amount of time required to script a scenario. Brief descriptions of our current capabilities are detailed below.

When generating a new scenario, the Scenario Generator automatically activates an Editor Wizard to assist the researcher. The Scenario Generator Editor Wizard provides popup windows that explain the process and provides a convenient and easy to use menu for entering scenario configuration data. After entering the requisite data for the scenario, the Scenario Generator Editor Wizard uploads the information into the Scenario Generator's display. The Scenario Generator's display consists of four functionally different segments: 1) 2D Geographic Chart covering the left hand side of the display, 2) the Entity Development Section covering the right hand side of the display, 3) the Time Control Segment on the upper left hand horizontal section of the display, and 4) the Control Buttons on the upper left hand vertical section.

The 2D geographic chart provides a global navigation capability to the researcher. By selecting the Magnifying Glass Button from the control button section, the researcher can zoom in or out to a particular area for the scenario. To zoom in, the researcher simply traces a box around the area using the mouse. To zoom out, the researcher simply right

clicks the mouse and the 2D geographic chart will zoom out one order of magnitude. Contacts are represented using standard ACDS icons with labels indicating the contacts designation. The latitude/longitude position of the mouse pointer is given in the text box at the lower right hand corner of the 2D geographic chart and is continuously updated as the mouse pointer moves. By selecting the Layers Button from the Control Button section, a popup window is generated that gives the operator the choice of displaying several enhancements and contact attributes directly onto the 2D chart. These choices include the ability to turn on or off the 2D chart, the grid lines, assignment lines, weapons effective range ellipses, entities, or labels. Additionally, many of the items allow the researcher to selectively filter which assets are activated or filtered out for a particular enhancement.

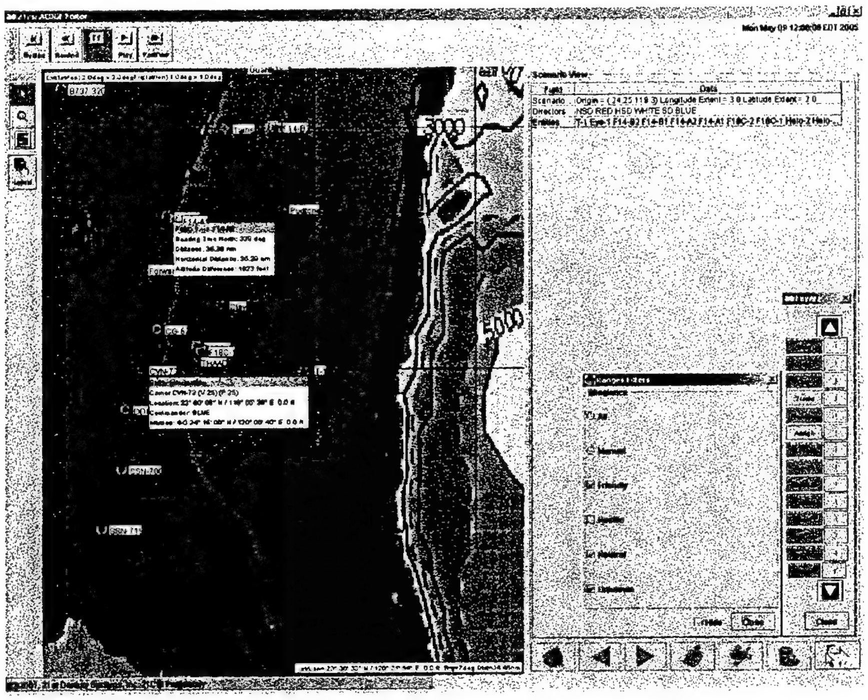


Figure A-4. Scenario Generator, Scenario View

Two of the four control buttons were discussed in the 2D geographic chart discussion above. The remaining buttons include an Information Pointer and an Editor button. The Information Pointer button allows the operator to hook a contact to find out the contacts known parameters. When the mouse pointer is placed over a contact, a green box is drawn to indicate that this is the contact under consideration. If the operator right clicks on the contact, the contact's information is displayed in a popup box. If the operator left clicks on the contact the box will turn red and this contact will become the referenced contact. The operator can now select another contact and the positional information relative to the referenced contact will be displayed in another popup box. Either of these boxes can be closed by clicking on the top line of the box.

The Time Control Buttons, located in the upper left hand corner of the Scenario Generator's display, are used to control the operation of the scenario with respect to time.

The researcher can start, stop, fast forward and rewind the scenario to check its operation. Simulation time is displayed in the upper right hand horizontal section of the Scenario Generator display.

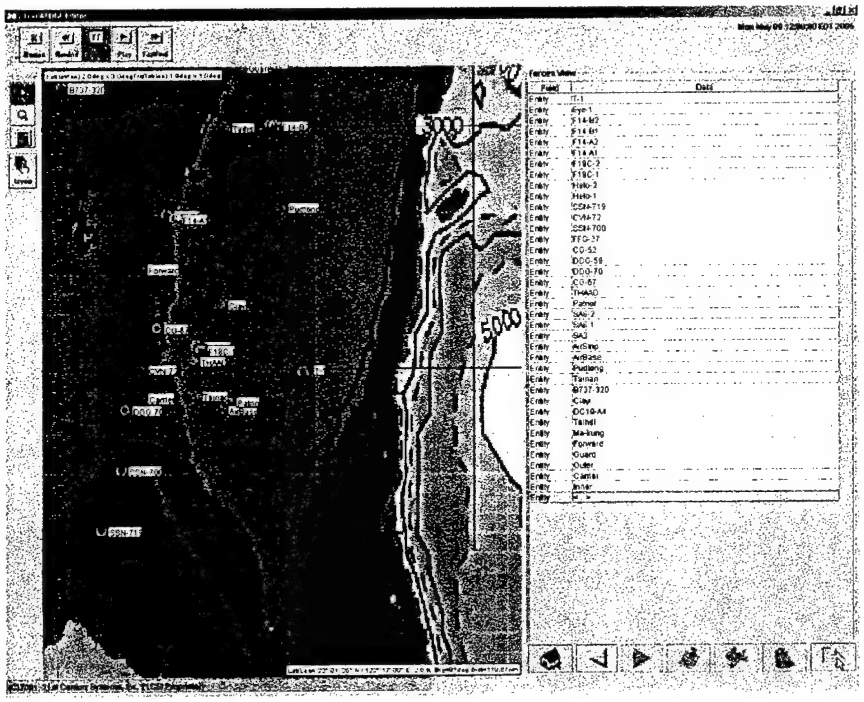


Figure A-5. Scenario Generator, Forces View

In the Entity Development Section of the Scenario Generator display, the supervisor can establish the basic force-on-force composition for the engagement. The Entity Development Section is divided into different views, which allows the researcher to add successively more detailed information to the scenario. For example, at the most macro level of scenario development, the Scenario View, the researcher begins to script the scenario. In the Scenario View, the generic where, who and what of the scenario are described including scenario constraints, forces, and directors are shown.

By highlighting the "Entities" line (thus enabling the "NEXT" button at the bottom of the Entity Development Section), the researcher enters the next level of scenario development and populates the Forces View with a force structure containing various entities. The researcher has generated a variety of land, surface, air, and subsurface assets for both the blue and red forces. A new entity is inserted into the view by selecting the last line of the entity list, "Entity < >" and the selecting the "NEXT" button on the bottom right side of the display. This action will allow the operator to enter the next level of entity development, the Entity View. A preexisting entity can be edited by highlighting the particular line and selecting the "NEXT" button. Note that the "HOME" button and the "BACK" button would be enabled allowing the operator to navigate into and out of the numerous views as needed.

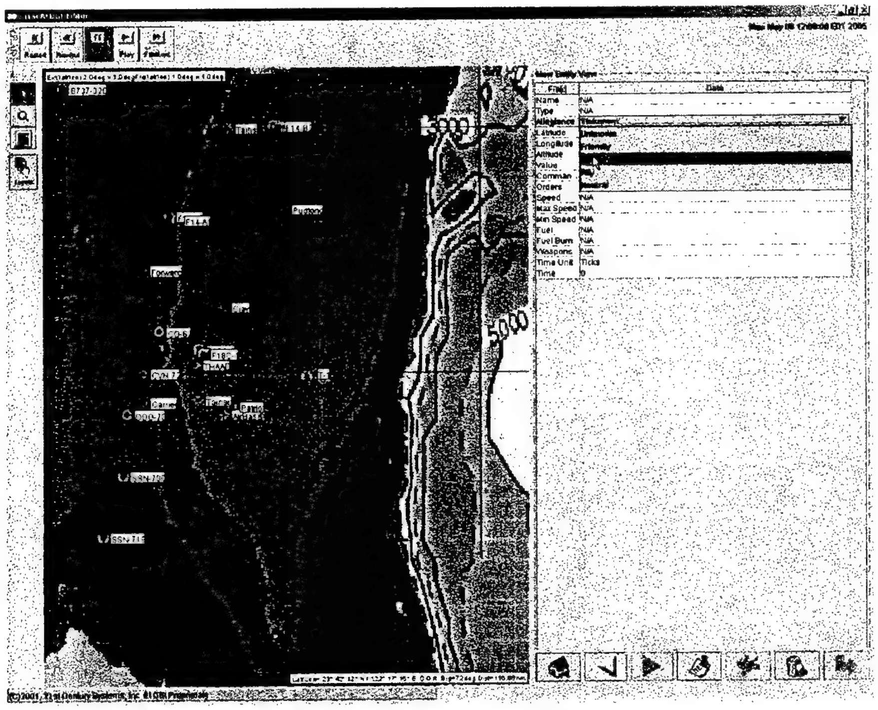


Figure A-6. Scenario Generator, Entity View

Once inside the Entity View, the attributes for a particular entity are keyed in by the operator to tailor the forces to be simulated. Items such as allegiance, location specified by latitude and longitude, altitude or depth, maximum or minimum speed, current speed, fuel status, fuel burn rate and weapons load out are possible. Using drop down menus, commonly used values for entity properties are suggested. Additionally, once a platform type has been specified, platform defaults are automatically loaded. For example, constants for minimum and maximum speed, fuel burn rate and weapons load out could be automatically loaded. However, the researcher has the option to change these parameters if the performance needs to be degraded or enhanced. By selecting the Editor Button in the Control Button section, the latitude and longitude for the contact is automatically entered into the LATITUDE and LONGITUDE blocks of the Entity View by clicking on the desired location on the 2D Geographic Chart with the mouse pointer. Similarly, waypoints and assignment orders can be designated using the Editor Button and the 2D Geographic Chart. Time phased orders such as course maneuvers, intercept orders, refuelings, and target orders can be added in the ORDERS block. In this way, the researcher can script the forces and order actions to be taken over time. However, as noted below, the decisions and orders that a subject introduces to the scenario can change the outcome of a simulated engagement and as such; the scenarios are not strictly scripted.

For the more adept at scenario building, a text-based scenario editor is also available. Lacking in the "bells and whistles" of the scenario generator, it can be used to generate a less complex scenario rapidly. Figure A-7 below is a depiction of this second scenario development method.

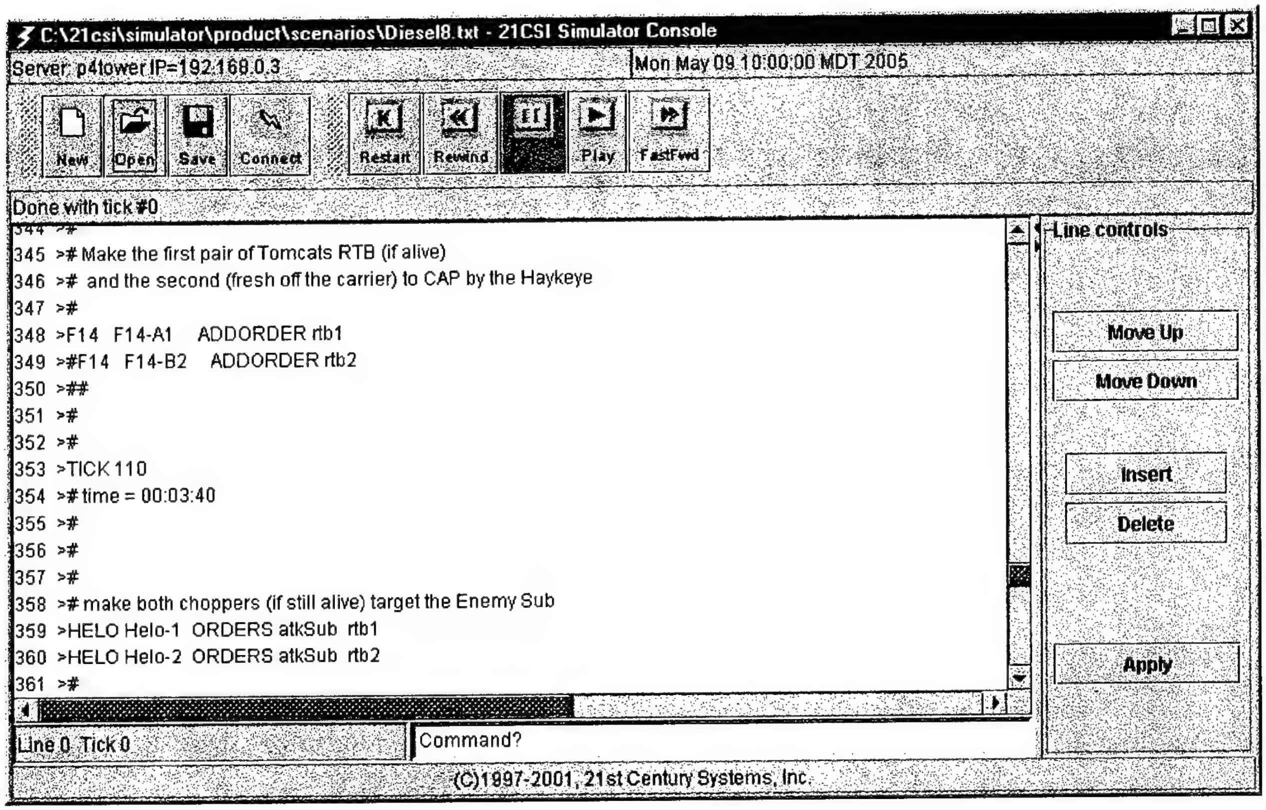


Figure A-7. Scenario Editor in Simulation Console of AEDGE

A.2.7. Benefits of the AEDGE™ Architecture

21CSI's AEDGE provides a common framework, information exchange mechanisms, and standard libraries of agent algorithms. The AEDGE kernel is extended by a family of components, which provide users with customized decision support toolkits. AEDGE has an open architecture, capable of connecting to any data source as well as exporting data to any well-defined format.

AEDGE provides multiple levels of customization. User-designed scenarios and scripts can be automatically generated by the AEDGE-based Scenario Editor. Rules and triggers for agent behaviors can be created and modified by the advanced user. AEDGE also provides APIs for custom extensions of agents, data bridges, and the COP framework. The sophisticated user will be able to use AEDGE as a flexible development and testing environment for DSS components. The practical user will enjoy AEDGE's versatile data connectivity and its near-real-time execution and monitoring of DSS functions. As a built-in bonus, AEDGE provides connections to a number of simulators and data formats, including HLA, DIS, DTED, DBDB2, XML, as well as support for multiple modes of distribution (CORBA, RMI, and TCP/IP).

A.3. Application Program Interfaces (APIs)

The AEDGE Development Environment provides an open API to a variety of data and functional components at progressively deeper levels of interaction. In Table 1 we summarize the available interfaces and their level of interaction. Three types of representative users are outlined: (a) a researcher will use the AEDGE and its extensions to develop scenarios, measures and possibly specialized client components; (b) an agent developer will utilize AEDGE as an agent development environment and will incorporate SME knowledge into the agent logic; (c) an AEDGE expert user will need the versatility of all APIs to create entire AEDGE components.

API Level	Researcher/User	Agent Developer	AEDGE Expert
Scenario Builder	Yes	Optional	Yes
AEDGE Framework	Yes	Yes	Yes
AEDGE Measures	Yes	Yes	Yes
AEDGE Data Feeds	Advanced Users	Advanced Users	Yes
AEDGE C2 Feeds	Advanced Users	Advanced Users	Yes
Simulation Entity	N/A	N/A	Yes
Entity Behaviors	N/A	N/A	Yes
Agent API	N/A	Yes	Yes

Table A-1. API Availability by Level of Interaction

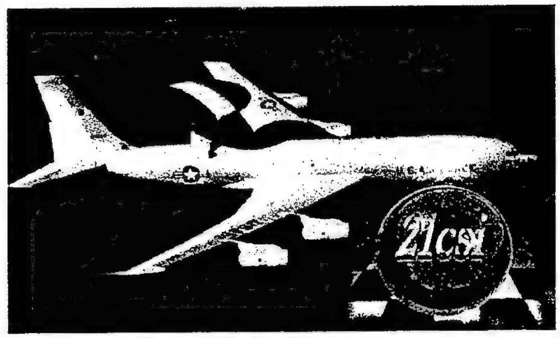
The interfaces currently available to AEDGE developers are described in more detail below.

- **Scenario Builder**. This API allows the user to interface with AEDGE's simulation and Agent components and to create, modify and execute simulation scenarios. The same API is used by the Scenario Editor Component (Section A.2.6) that allows the (non-programmer) user to visually modify a scenario. The API is defined in a language/platform independent AEDGE Service requests and returns.
- **AEDGE Framework**. The Framework API allows the user to define, instantiate, modify and query AEDGE Framework Entities, which are the common data structures in the AEDGE information backbone. A wide variety of generic and specific object types are available as object-oriented hierarchies. The users can extend the provided objects with their own data requirements.
- **AEDGE Measures**. This Service-based API is available to users who wish to store, retrieve, query and analyze events and measures stored on the Measures server.
- **AEDGE Data Feeds**. The Data Feed API defines the direct access/query as well as the publish/subscribe services for any AEDGE component that provides a Data stream. Data streams are simulated or live Framework data objects (or "tracks"), which represent entities in the simulated/live universe.

- **AEDGE C2 Feeds**. This API defines the Command and Control service exchanges between a simulation (or live) data feed providers and its users. The Service-based API is available to users who need to provide feedback to a simulation, such as mission and order changes, modify the ROE or other guidelines and thresholds.
- **Simulation Entity**. This Java API enables the advanced user (programmer) to instantiate, modify and extend existing simulation entities, such as aircraft, ships, weapons, and so on. This API is required to change or add the existing set of simulated resources.
- **Entity Behaviors**. To modify or add new behaviors to the simulated entities, the advanced user will employ the Behaviors Java API.
- **Agent API**. The Agent API allows the advanced user to define, extend and modify agent components. Core agents are capable of connecting and exchanging information with the user and other agents; they also implement baseline algorithms (search, monitor, allocate, project/evaluate, etc.). Application specific agents use this API to extend the core agents with application-specific algorithms, and interactions.

To help users learn and utilize the provided APIs, a variety of samples are available. Sample applications are developed to demonstrate the use of combinations of APIs. For example the Sample Map Client utilizes the AEDGE Data Feed and AEDGE Framework interfaces to receive and draw entities on an interactive geographical map with specific entity information displayed as text. Other samples demonstrate the use of Agents, Measures and C2 Feedback to create a simple agent-based decision support system.

APPENDIX B – AWACS-AEDGE STE



One of the first extensions to the AEDGE environment was an STE for AWACS weapons Directors (WDs). This work included development of measures of effectiveness and performance for individuals and teams, in the context of AWACS operations. This training platform was based on a set of flexible, portable software technologies, which include heuristics, resource allocation, dynamic planning, visualization and display, and several types of intelligent agents. Figure B-1 illustrates a typical AWACS prototype display.

The utility of the AWACS-AEDGE for cognitive training and performance research is its greatest asset. The benefits of this general approach to STE-based research is detailed elsewhere (Schiflett & Elliott, 2000). The AWACS-AEDGE was developed to primarily to support trainers and researchers. Every characteristic and feature within the platform was developed to empower trainers and researchers with scenario generation,

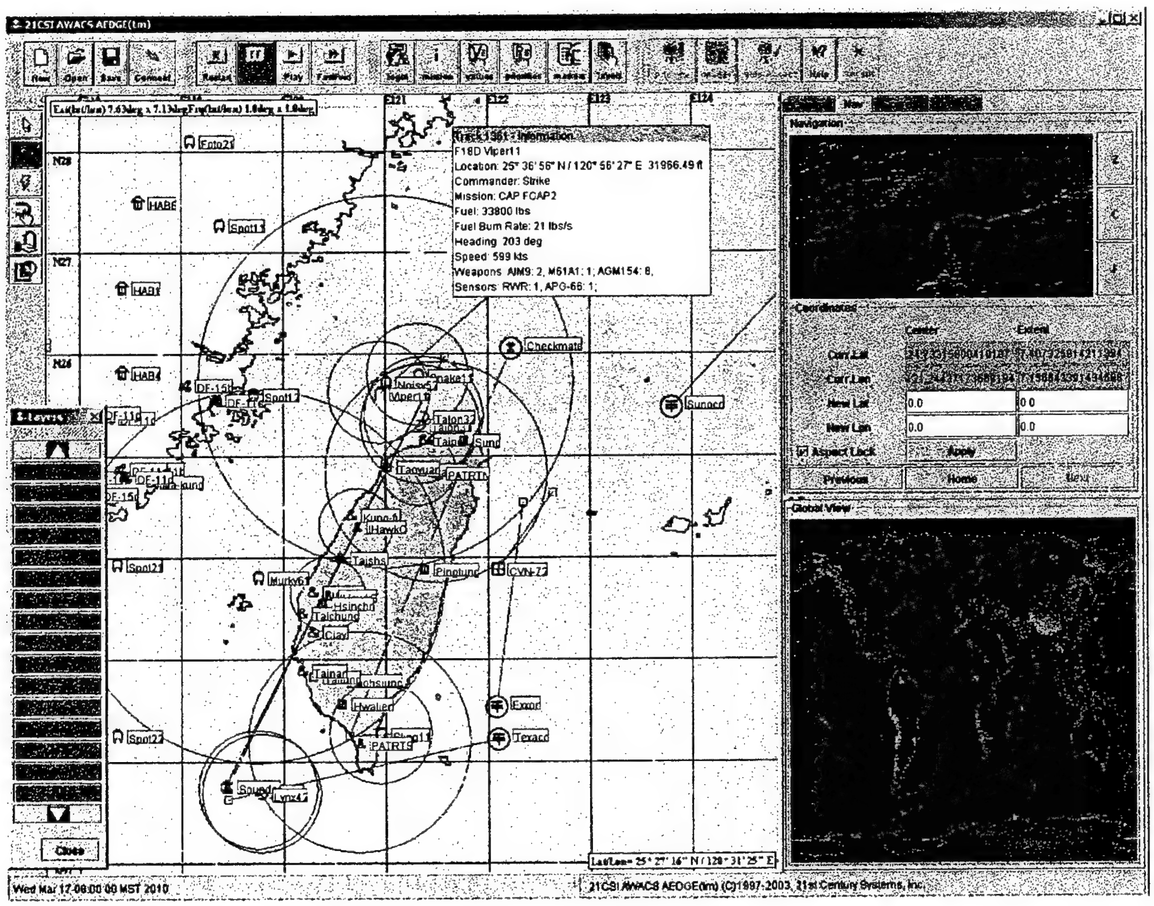


Figure B-1. AWACS-AEDGE Display

manipulation, online performance feedback, and data retrieval. Internal validity is enhanced by providing researchers with detailed performance measures, increased scenario realism, ease in generating and injecting scenario events, agent-based performance models, and comprehensive data output files. Additionally, further control is provided to team performance researchers through the provision of synthetic team members—thus allowing investigations of performance within more highly controlled team contexts (Barnes et al, 2002). It provides trainers and researchers with online scenario revision capabilities and visual online performance feedback for operators. Finally, this system was developed to enhance external validity—the degree to which research transitions to the operational performance environment. This was accomplished through comprehensive cognitive task analyses of the operational performance domain. While no system is a guarantee of good training or research per se, this application provides tools that empower experts to more easily accomplish research and/or training goals (Elliott et al, 2003).

The AWACS Weapons Director training tool is a distributed interactive simulator featuring agent-based decision support technology. The tool was originally designed to support teams of Weapons Directors and Senior Director(s), which are the operators and decision-makers aboard AWACS aircraft. The environment has evolved and today it includes:

- Simulator, supporting a variety of airborne, land and sea platforms
- Scenario loader and a visual scenario builder
- Real-time entity observation and altering tool (Super-user mode)
- Variety of agent families – decision support, surrogate, tutorial, etc.
- A graphical user interface and a prototype visual 3D interface
- Performance and workload measures
- Communication channels (chat mode)

These features are implemented over a common client-server architecture, where the server takes most of the processing load of maintaining the simulated universe, while the clients are responsible for interacting with the user. The agents can be located either at the server or at the client side, depending on their functionality.

Earlier versions of the AWACS tool were evaluated both by the Air Force and other defense contractors. 21st Century Systems, Inc. has found the Air Force's evaluation to be quite positive, with 40 active duty AWACS WDs at Tinker AFB having used an earlier version of this tool. Both the collected feedback and a post evaluation study of the simulator-logged events have established that 21st Century Systems, Inc.'s concept of assistive agents is of significant utility to the WD and C2 users. The current version of AWACS-AEDGE is used today in cognitive science research under the auspices of the AFRL at Brooks.

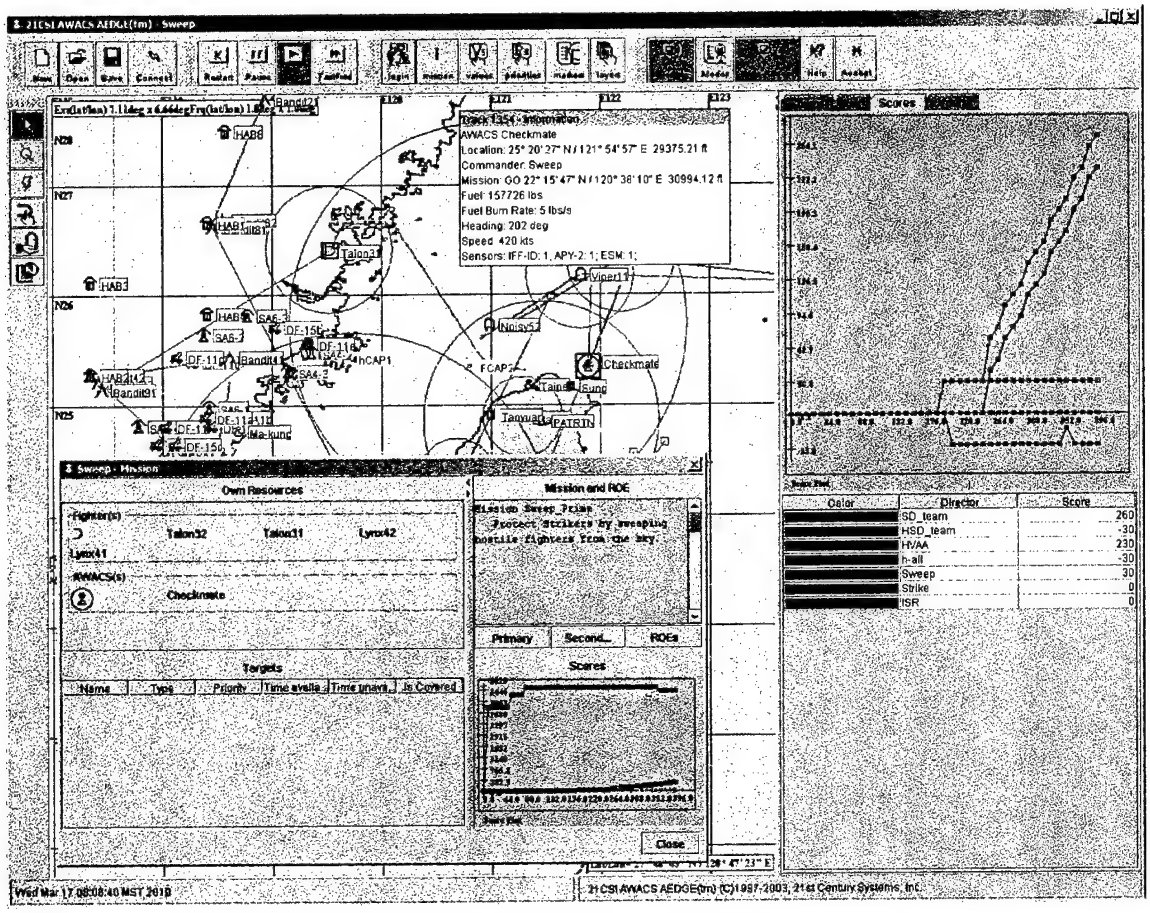


Figure B-2. AWACS-AEDGE Sample Measures Display

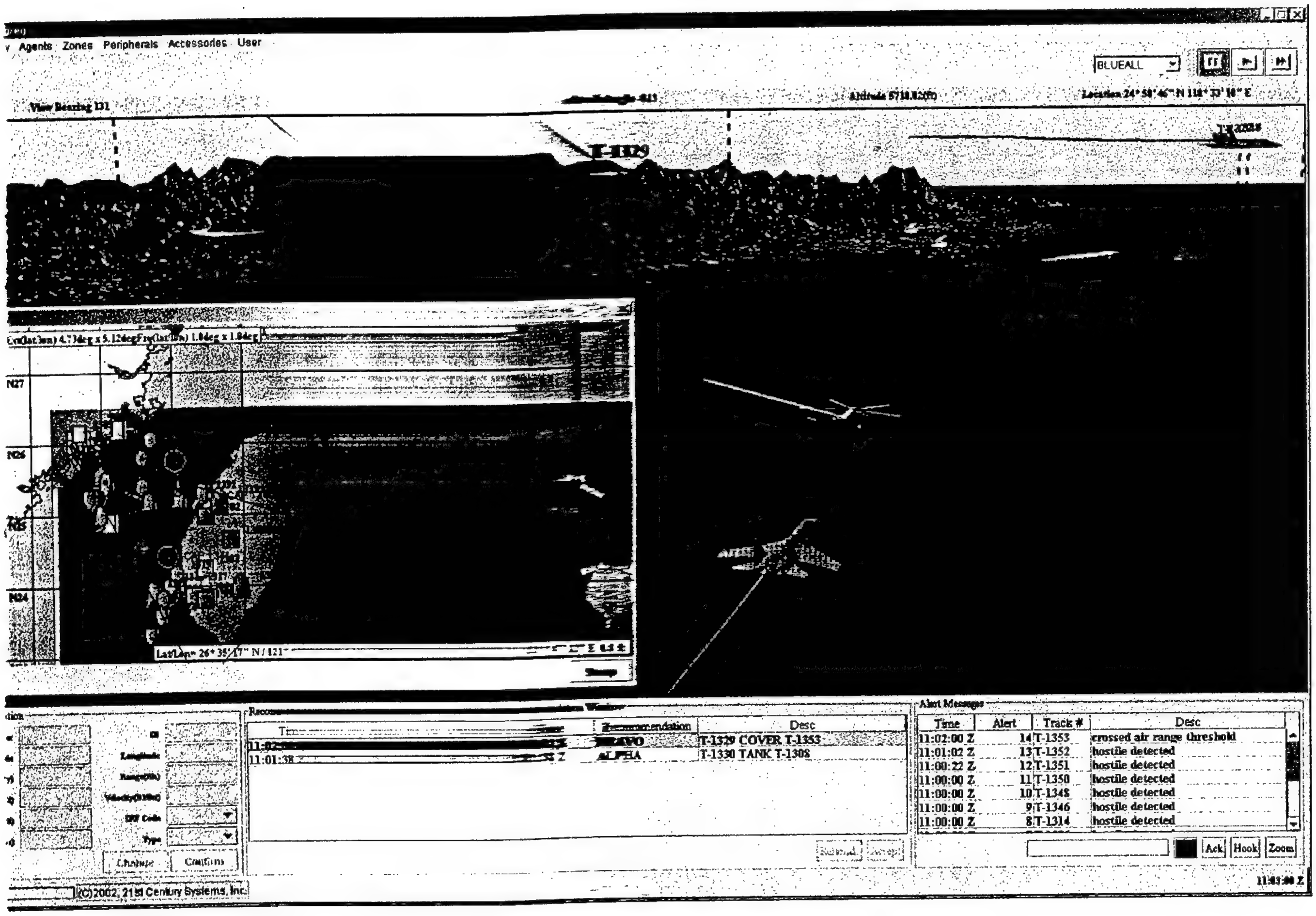
Appendix C – Advanced BattleStation with Decision Support System (ABS/DSS)

C.1. Overview

Another existing extension to AEDGE is a system that 21CSI is currently in the demonstration phase of development for PEO Carriers (US Navy). This program is called the Advanced Battlestation (ABS) with Decision Support System (DSS) (ABS/DSS). The ABS/DSS was chosen for demonstration purposes for its similarity in purpose and function of the requirements levied for the predictive battlespace awareness tool. The revolutionary ABS/DSS substantially improves carrier Tactical Flag Command Center (TFCC), Combat Direction Center (CDC), and Combat Information Center (CIC) operations, provides for a reduction in required manpower, as well as significantly reduces costs of its operation. The TFCC, CDC, and CIC environments ultimately needed an integrated electronics/information management system, i.e. ABS/DSS, which uses a common, scalable, Commercial Off The Shelf (COTS)-based architecture with a human factors engineered interface. An integrated ABS/DSS system provides a much more cost-effective situational awareness, allowing fewer people to run the system and fight the war. It has been estimated that by using automation (such as real-time analysis, integrated controls, intelligent software decision support) and advanced displays (such as large area displays, graphically based formats, integrated/fused information), command and control manning will be reduced to 50% or less of current levels. 21CSI's ABS/DSS's integrated, common, open IS architecture system design also reduces the costs and increases the throughput of future systems.

The development of 21CSI's ABS/DSS is being pursued through a progression of software and hardware deliverables. The current configuration is a revision of the initial ABS prototype, which was derived from work began during RIMPAC 2000 aboard the USS Lincoln (CVN-72). Numerous recommendations from CRUDESGRU 3 Flag Staff, the Carriers Type Commander, and USS Lincoln TFCC watchstanders and others were incorporated into the current configuration shown in Figure C-1.

The current configuration of 21CSI's ABS/DSS allows the watchstander to navigate the 3D battlespace using an attached joystick, a mouse, or using the keyboard. Consolidated situational awareness is gained through exploration of the integrated air, ground, maritime, and subsurface environments of the battlespace. Visual cues such as a numeric heading marker, view altitude, and attack angle (located centerline and above the display), whiskey grid lines (engraved into the surface topography), and grid ID markers are used for operator references to facilitate orientation in the 3D environment. Objects in 3D space are represented by standardized Navy AADC icons. The ABS/DSS utilizes Digital Terrain Elevation Data (DTED) to provide a 3D terrain for the watchstander to navigate. The operator can select the transparency of the terrain such that a terrain feature will not completely hide the presence of a high interest contact or enemy ground asset. Similarly, digital bottom contour data is used for the ocean, river, and lake bottom visualizations.



F: Figure C-1 ABS/DSS Screen Capture

ABS/DSS

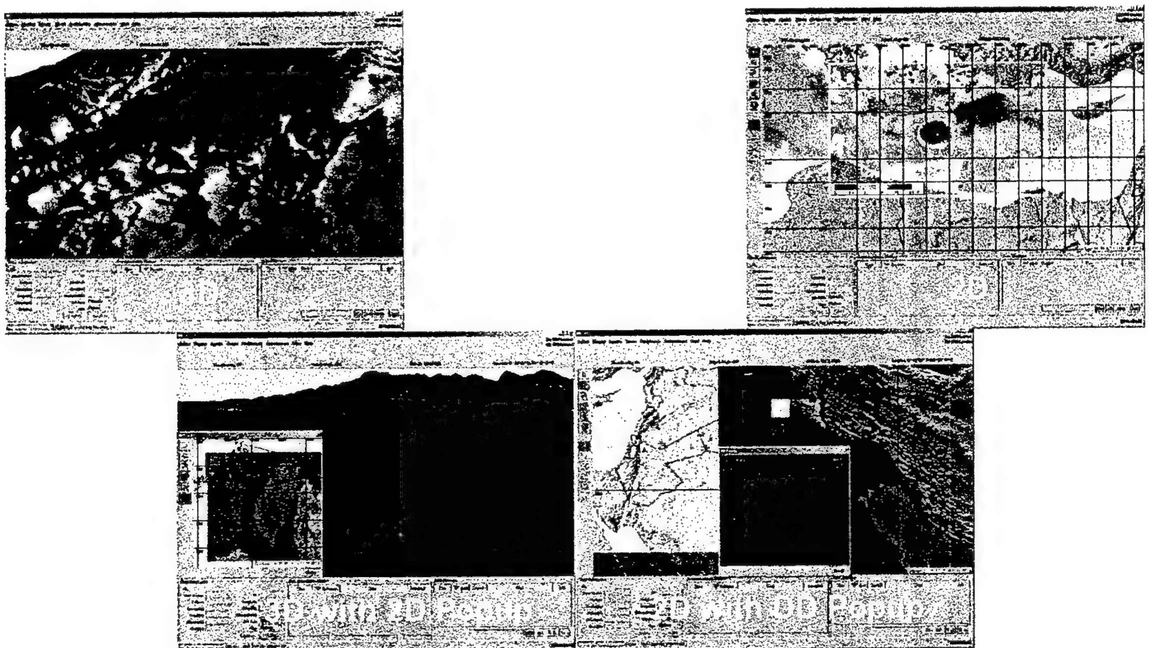
ABS/DSS main screen is made up of five subsections: Main Battlespace, Track Info, mmendations, Alerts, and Menus. Each of these subsections will be described in the :hat follows.

Main Battlespace sectı ıon of the display is the focal point for the watchstander. It is is section that the watc chstander obtains a visual representation of the data that has collected for analys sis. ABS/DSS allows the watchstander to navigate the espace using an attacı ned joystick or by arrow keys from the attached keyboard. solidated situational awareness is gained through exploration of the integrated urface, maritime, air, and ground, environments of the battlespace. Visual cues such ıe observer's numeric heading marker, view altitude, and attack angle (located erline and above the display), observation latitude/longitude, whiskey grid lines raved into the surface topography), and grid ID markers are used for operator ences to facilitate or ientation in the 3D environment. Objects in 3D space are esented by standardize ed 3D icons.

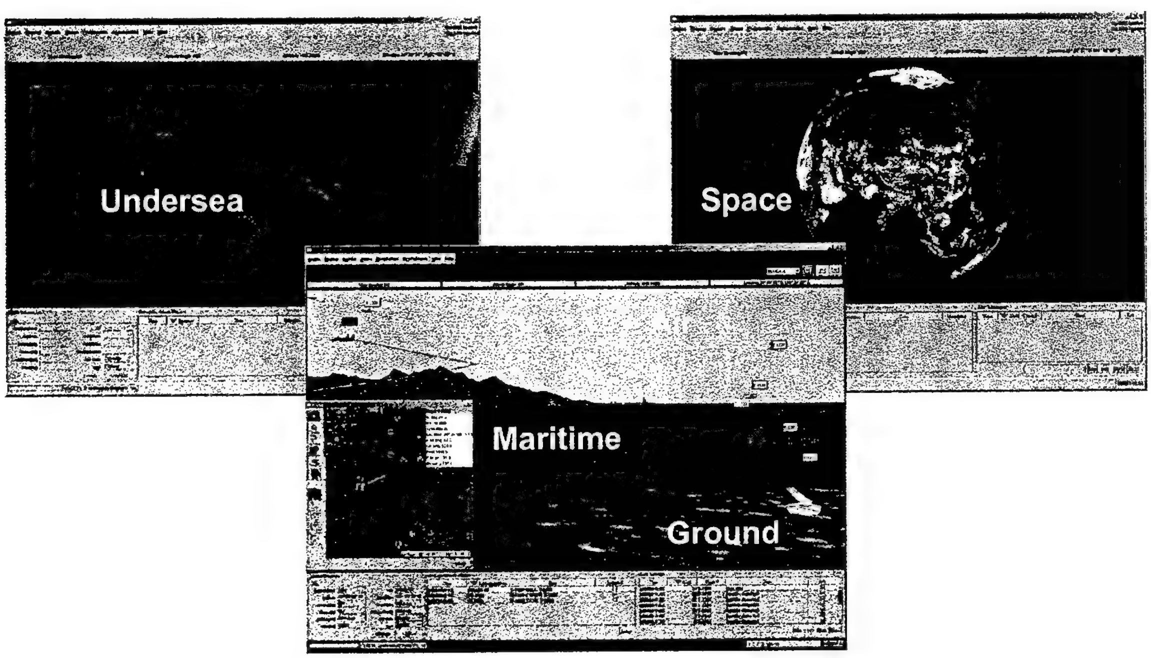
vatchstand nder has the option to select a 2D bird's eye view of the battlespace. ionally, us using a popup window the watchstander can create a picture in picture with any y combination of 2D and 3D configurations that is desired. Above are ples of 3D D only, 2D only, 3D in the Main window with 2D in the popup and 2D in Main Wind ndow with 3D in the popup. In this way, the ABS/DSS allows the stander to to choose, resize and reposition the visualization displays as necessary to fit eferences s and perception modes. As demonstrated in the user acceptability test, operators s liked only the 2D, some only the 3D and most somewhere in between combinat ation of views.

D map di displays contacts using standardized MILSTD 2525B or ACDS icons and atchstande der can selectively change the geographic scale of the 2D map using the function. Additionally, the watchstander can swap the 2D and 3D maps such that D map is s in the main window and the 3D is in the popup window. Additionally, map can n be used standalone.

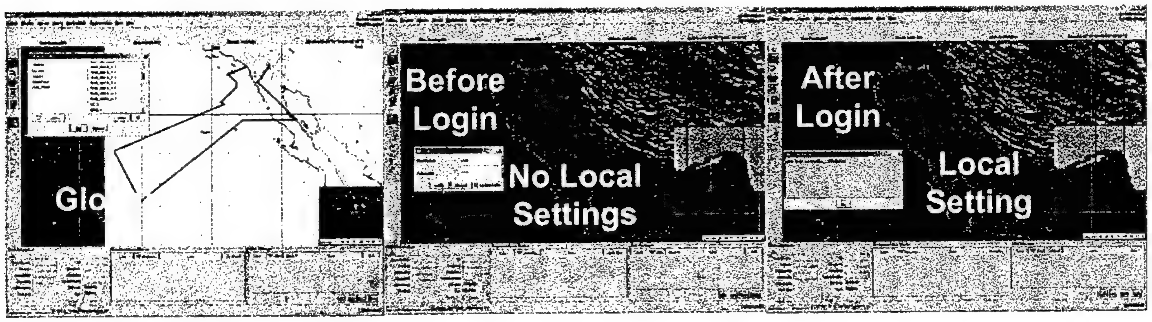
rver and object motion in the 2D and 3D space is synchronized. As the ıstander n navigates using the joystick in the 3D display, the observer icon (a white) moves cc correspondingly on the 2D display. Additionally, if the watchstander needs



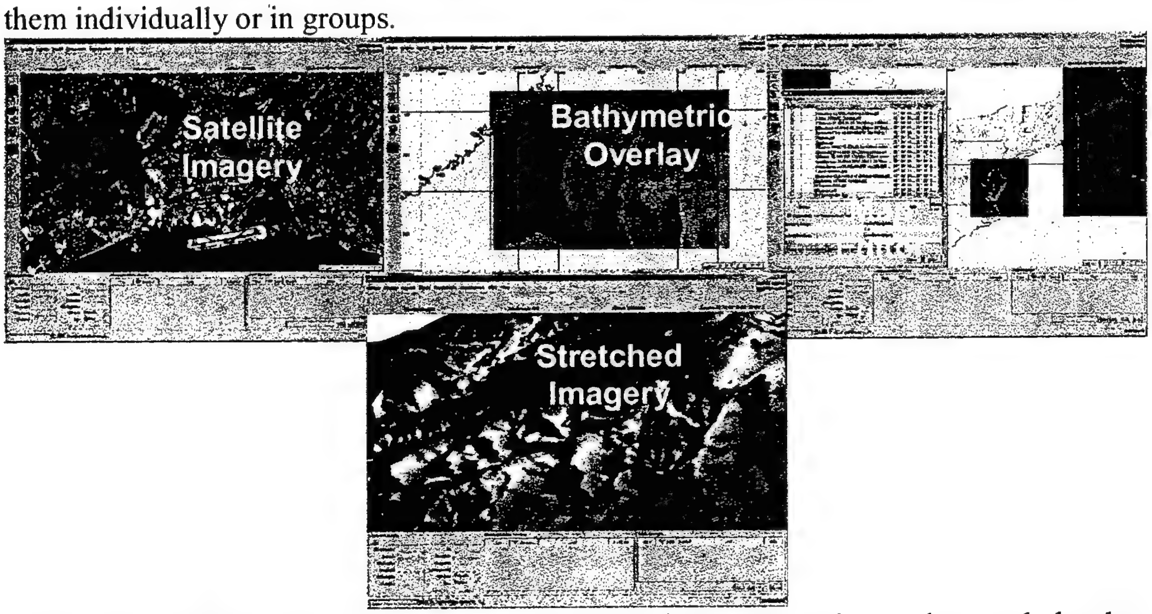
to quickly jump from one location in the battlespace to another location some distance away, the watchstander need only to click on that location on the 2D display and both the 2D and 3D visual displays are transported to that location. A field of view indicator is included on the observer icon in the 2D map to provide additional visualization cues for the watchstander for distance to the horizon and what contacts are in his current 3D field of view. The field of view indicator turns with the observer and its center corresponds to the heading marker in the 3D map. Additionally, as the watchstander changes his attack angle to negative values the field of view indicator's distance to the horizon shrinks to reflect reality. In other words, navigation in the 2D/3D domains is completely linked with each domain supporting the visualization in the other domain.



The watchstander has the ability to develop the battlespace situation for an integrated ground, maritime, air, space and undersea engagement. This is possible since the battlespace is a true 3D space which makes us of worldwide Digital Terrain Elevation Data (DTED) and Digital Bathymetric Database (DBDB) data.



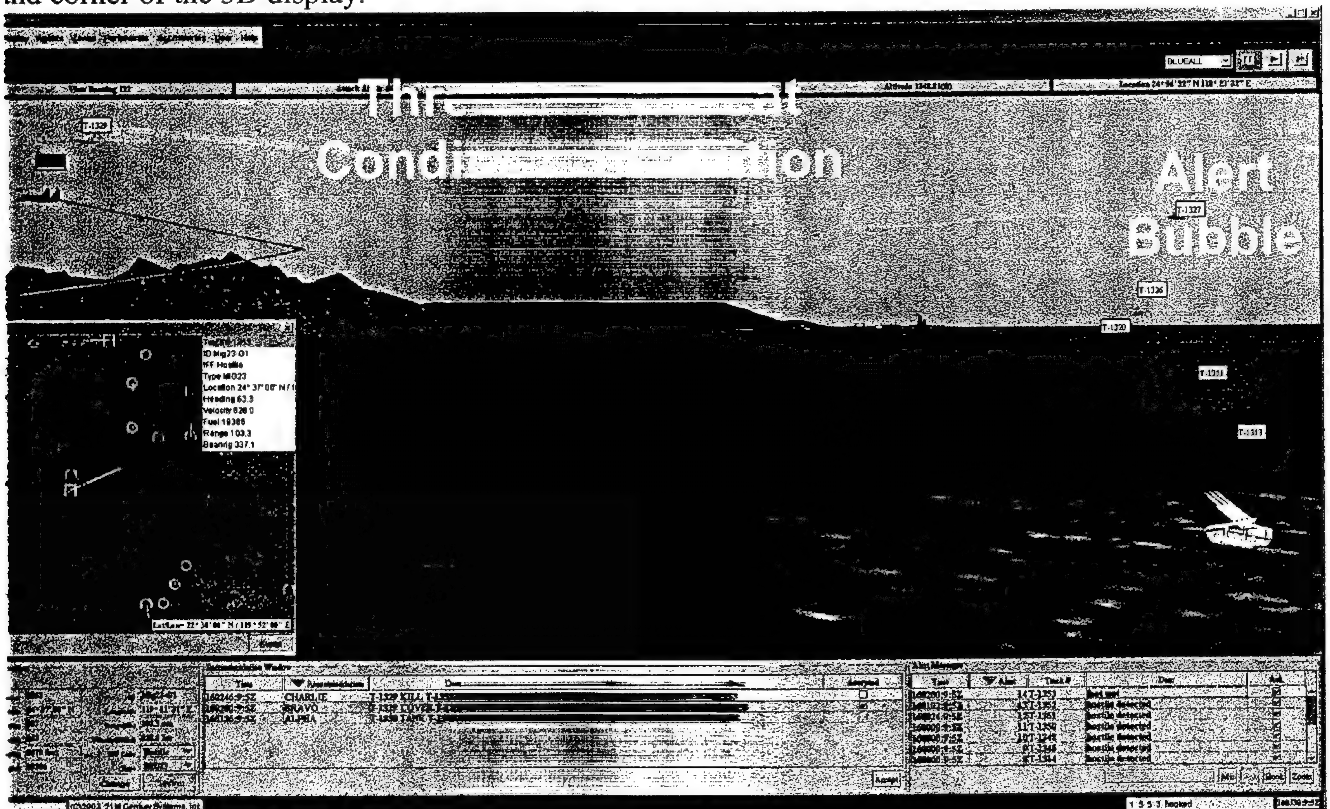
Each watchstander is free to configure his station as is necessary to perform his assigned duties. To support this necessity, 21CSI has incorporated a user login procedure that reloads user preferences as needed. However, certain attributes about the operation of the ABS/DSS should be universal in nature and therefore apply uniformly across the varied watchstanders. For this reason, 21CSI has implemented the notion of global and local settings. For example as depicted above, initially, the SOCAL operating areas are shown to the watchstander as a global setting. These areas and attached agents are present independent of the watchstander who is signed in. However, for that particular watchstander no areas may be present for the Gulf region. Another watchstander who had previously designed and saved a unique set of areas and agents to assist in the performance of his duties logs in and the areas are automatically placed. If the watchstander desires to remove some or all of the areas and agents he simply removes them individually or in groups.



Using the ABS/DSS' map editor the watchstander is free to apply overlays and chartlets onto the 2D display. Additionally, the watchstander can specify the tiling order for which the available overlays will be applied. In the capture above and right, several lays can be

ged in order to provide a complete p icture. High resolution satellite imagery can be ly installed and accessed to provide an unprecedented view of any area of interest. ent capability also makes it possible to take the same satellite imagery and stretch nagery to the 3D terrain. The 3D app plication of imagery along with the 2D gives the stander the look and feel of actually being there.

vatchstander has the ability to displ ay information about any known contact in the n. This information is contained in the Track Information Box, shown in the lower and corner. The contact's Track n umber, IFF designator, identification, location ng), bearing, course, speed, range, altitude, are displayed. If information is desired contact that is currently in the field of view of the watchstander in the 3D space, the watchstander simply sele cts the contact using the mouse pointer and the nation block will automatically be updated. The contact is now highlighted green dly) to indicate that this is the conta ct for which the track information is displayed. vever, the contact is not in the field of view, the watchstander selects the "Actions" 1 and then manual enters the desired contact number in the popup box in the lower ınd corner of the 3D display.



Recomme nded Actio n

Alert Notification

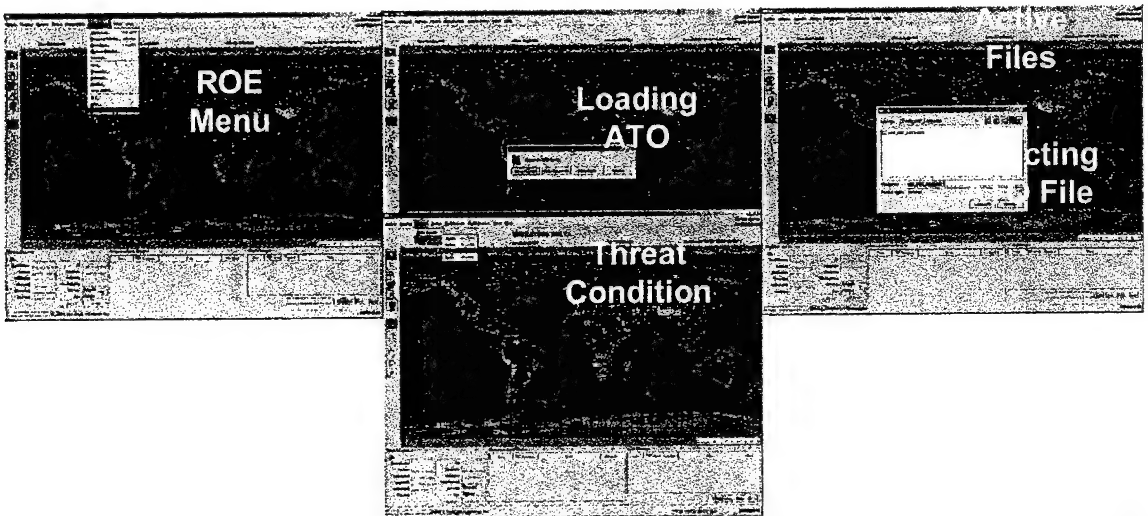
-based decision support technolog y will be employed in order to facilitate the stander's situational awareness. Agents notify the watchstander of contacts that tripwires. The tripwire values are operator selectable by selecting the "Alert

Presets" menu option from the "SA" menu and using the appropriate password. Adjustable tripwires for contacts could include:

- Minimum or Maximum Airborne Speed
- Minimum Airborne Range
- Minimum or Maximum Airborne Altitude
- Minimum or Maximum Surface Speed
- Minimum Surface Range
- Minimum or Maximum Submerged Speed
- Minimum Submerged Range
- Threat IFF
- Contact Weapon Range
- Initial Detection of Hostile Contacts

The agents utilized by the DSS analyze all known contacts against the Alert Presets and displays a message in the Alert Message Box if a tripwire is violated. The displayed message indicates the time of the alert, the contact number, and the tripwire exceeded as shown in the lower right hand corner of the display. The Alert Message Box, in its normal configuration operates as a waterfall display with the most recent alert appearing at the top. If the watchstander desires to sort the alerts, he may sort the alerts in ascending or descending chronological order and/or by contact number. Additionally, an alert also generates a colored alert sphere around the contact of interest in the 3D display and a box around it in the 2D to assist the warfighter in locating and identifying the contact.

ABS/DSS will be supported by 21CSI implemented COTS voice synthesis and recognition software that allows the watchstander more freedom in performing his duties in a less distracted, hands-free environment. Using Text-to-Speech voice synthesis, 21CSI's ABS/DSS utilizes a computer-generated voice to deliver aural alert notifications to the watchstander's headset or external speakers. Abbreviated voice notifications are provided to lessen the distraction of the watchstander by informing the watchstander of an alert instead of watchstander having to inefficiently check the Alert Message Box continuously for new alerts. If the abbreviated voice notification stimulates a need for further information about the alert, the watchstander has an archived list of the alerts in the Alert Message Box to review. For voice recognition, 21CSI's ABS/DSS will use grammatical rule sets to implement system control functions to facilitate operation in a hands-free environment. For example, the watchstander simply speaks into the headset to "Hook 'Contact Number XX'" or "Zoom 'Contact Number XX'." The verbal commands provide an alternative hands free operating mode for the respective manual button operations described above. 21CSI builds into the design multiple redundant methods to perform each task. As described above, for all commonly performed tasks, the warfighter can choose from manually typing the commons using keyboard strokes, utilize mouse clicks, or use voice recognition to issue a command. Each method is identical in function and provides the warfighter choices of operation mode for varying environments.

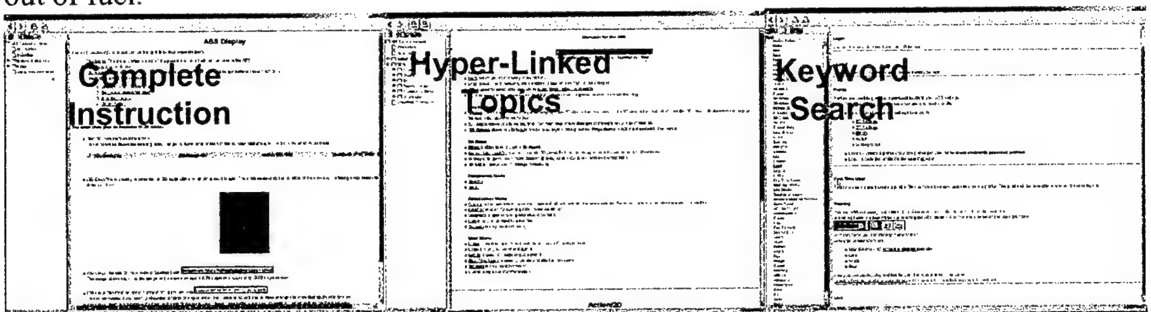


21CSI's ABS/DSS will utilize agents to analyze the battlespace to provide recommendations to the watchstander concerning the tactical situation. The ABS/DSS will list the recommendations in the Agent Window located in the lower center of the 3D display. Additionally, 21CSI's ABS/DSS will provide audible notification of the recommendations via the voice synthesis software. Recommendations are specific to the particular warfighting specialty that the watchstander is responsible for at the respective station. Additionally, the recommendations are based upon the current battlespace situation, the current rules of engagement, and threat condition. 21CSI's ABS/DSS will provide recommendations only and the human-in-the-loop can choose to accept the recommendation and issue the order or ignore the recommendation if other considerations not available to the ABS/DSS must be incorporated into the decision. Also depicted are notional weapons and/or sensor cones for contacts of interest. These cones are based upon third party simulations and software and can be selected, deselected, and have the cone's opacity adjusted to suit user preferences.

21CSI's ABS/DSS will normally operate in its default mode of battlespace visualization as described above. However, in times of reduced operational tempo or while in port 21CSI's ABS/DSS can provide the capability to train the watchstanders using realistic mixed mode scenarios. The watchstander can activate the Tactical Training mode by selecting the "Training" menu option and then selecting a scenario for the simulation.

Operation of 21CSI's ABS/DSS agents will be identical in the Training mode as in the Battlespace Visualization mode except that the input data feed is simulated track information versus real track data from sensors and system data information from the tactical and non-tactical LANs. Examples of screen captures of both live mode and training mode are given above. The only differences in the displays are that the borders around the different subsections of the display are blue instead of grey and the VCR buttons are added to stop, stop, or pause the scenario. The command and control interaction between the trainee and the agents are flexible and is selectable from the drop down menu at the top right of the display. Using the scripted scenario in the "STANDALONE" mode, the agents optimally recommend taskings for the available units to fight the engagement/casualty according to preset doctrine and rules of

engagement or casualty procedure. In "STANDALONE" mode, the recommendations are automatically accepted and the simulation proceeds as if on autopilot. However, the watchstander can log into the scenario to direct the "BLUE" forces, the "RED" forces, or the "WHITE" forces. Future plans will further subdivide the forces into "BLUE-SUB", "BLUE-SURFACE", "BLUE-AIR", "BLUE-SPACE", etc. Further breakdown is possible down to the platform level. Once the trainee has logged into the scenario as, for example, "BLUE," the agents will continue to recommend the optimal tasking, but the command and control orders must be given by the trainee. In this way, the watchstander is free to accept the recommendation, ignore the recommendation, or override to a higher precedence order. The simulator will continue in accordance with the scrip, but the outcome of a particular engagement is dependent upon the type and timing of the command and control orders given by the trainee. For example, if a recommendation is given to steer a torpedo that is false homing on a decoy but the trainee chooses to ignore the recommendation, then the affected torpedo will continue to false home until it runs out of fuel.

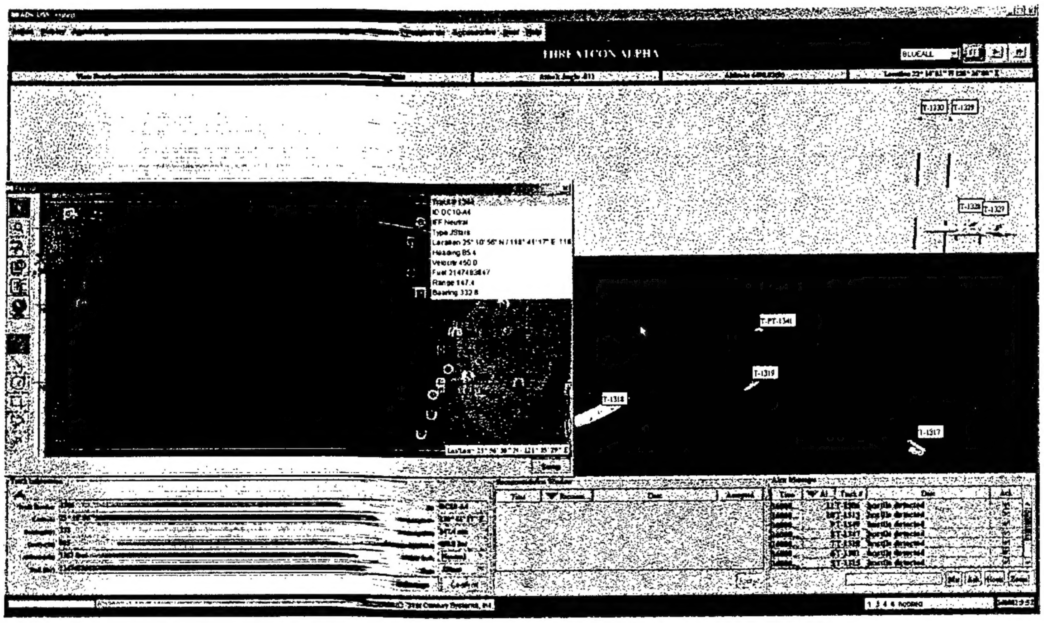


The watchstander is assisted in performing his duties through the use of an extensive help system. The help function consists of a detail and complete instruction set that the operator can utilize in order to obtain help in performing his duties. Whether using a keyword search or hyper-linked menus the watchstander the watchstander can find the topic of interest in a quick and efficient manner.

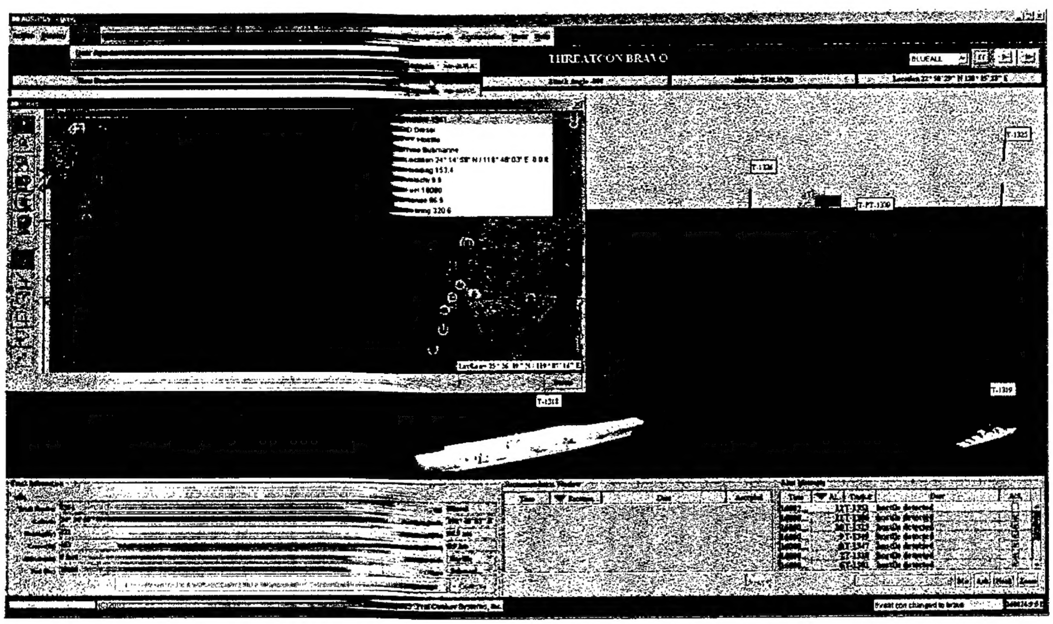
C.3. An Illustration

Scenario Background:

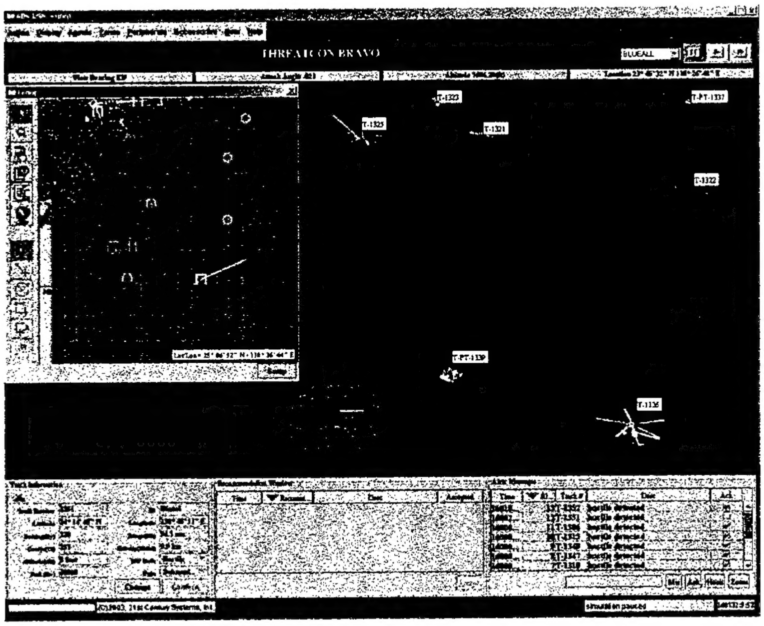
- Abraham Lincoln Battlegroup in Taiwan Straits
- Hostilities between Taiwan and China necessitate US presence
- Intelligence Reports show diesel submarine making preparations to get underway from Chinese Port
- US has deployed Helicopters to intercept and track diesel submarine



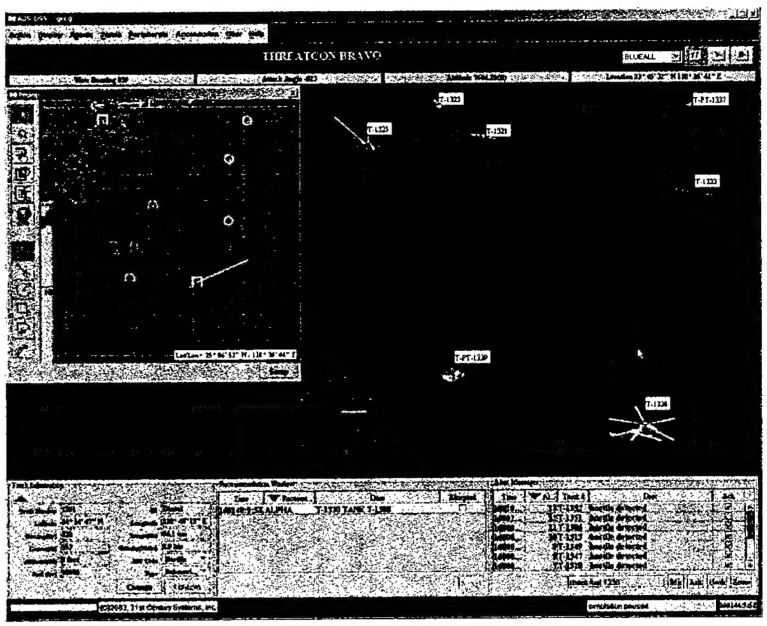
= 0
Battle Group on Station
History Lines Building



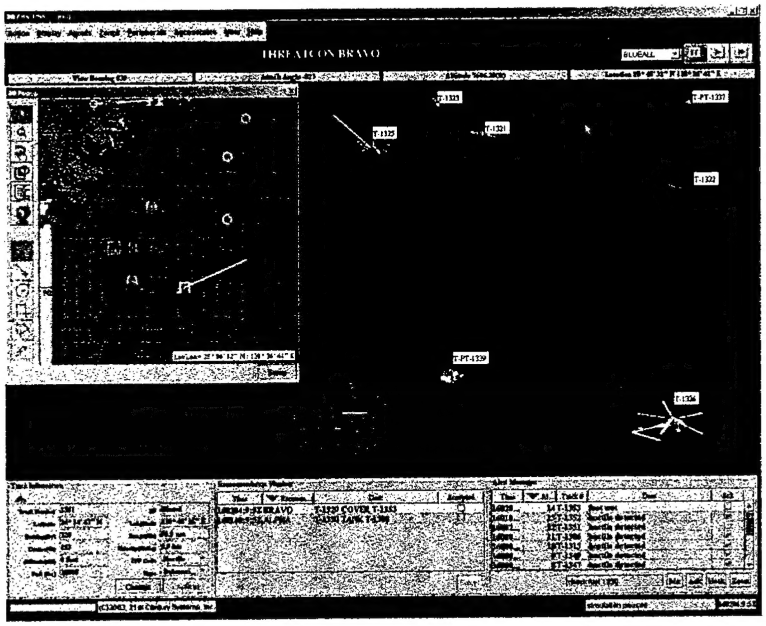
me = 0:20
Enemy Diesel Sub Detected
Alert and Alert Bubble Generated
Helos Directed to Intercept Sub
Watchstander changes Threat Condition to BRAVO



Time = 1:22
- Unknown Aircraft Takes off from Civilian Airport
- History Lines Building

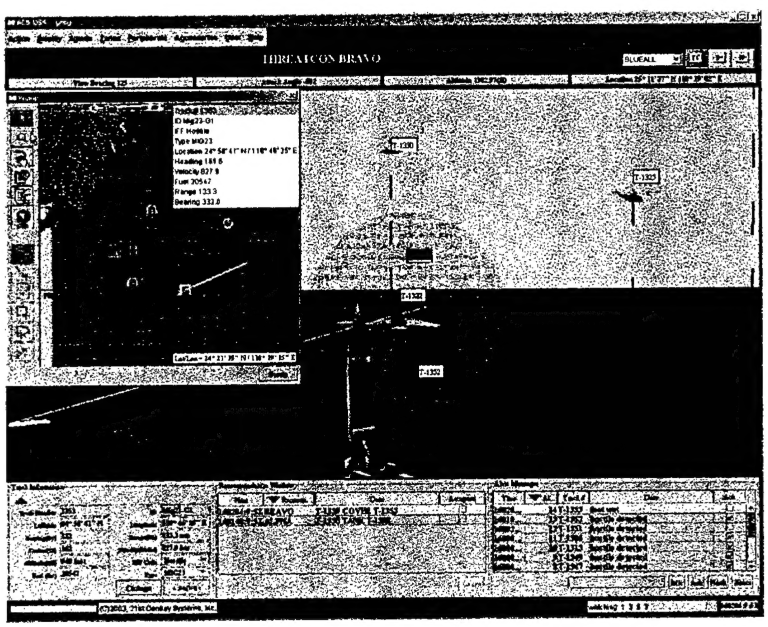


Time = 1:44
- Agents recommend Tanking for Aircraft low on fuel



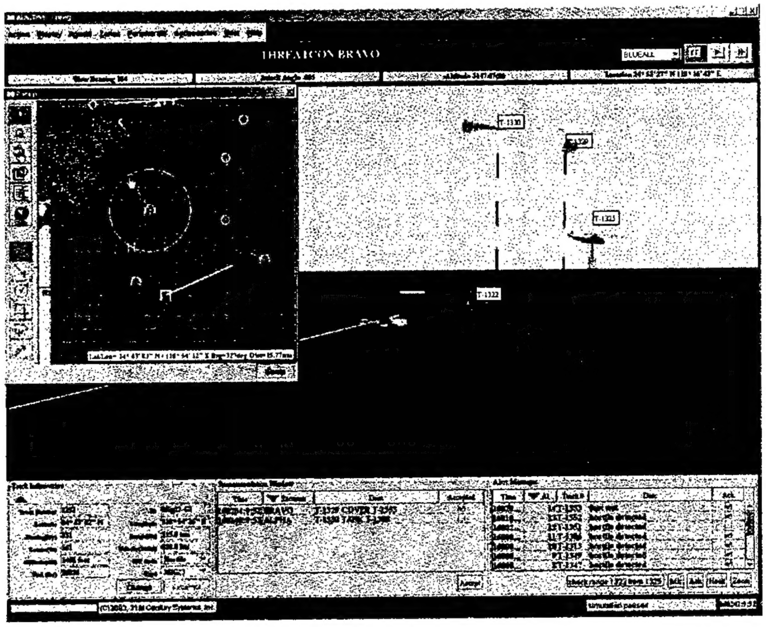
Time = 2:04

- Agents detect shift to Hostile for MiG
- Agents generate Alert
- Agents analyze assets and in-situ data and recommend intercept unit



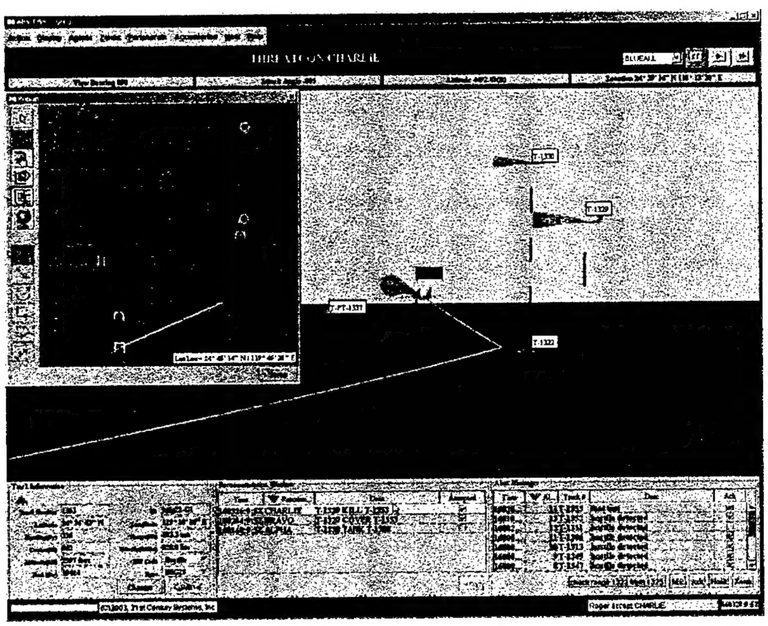
Time = 2:06

- Watchstander Uses Watch Command on MiG



Time = 2:42

- Watchstander order 1329 to cover 1353
- Watchstander enables weapon cones
- Watchstander checks range between Helo and MiG on 2D popup



Time = 3:28

- Helo attacked by MiG
- Watchstander changes Threat Condition to CHARLIE
- Agents Recommend 1329 Kill 1353